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THERMAL PROTECTIVE COATINGS

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Prepared by:

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Thin coatings of these filler systems combined with various organic intumescent paints and inorganic matrix systems were developed and thermally evaluated. Test specimens were exposed to a frontface thermal flux environment of  $13.5 \text{ BTU/ft}^2\text{-sec}$  ( $15.3 \text{ joules/cm}^2\text{-sec}$ ) within the door opening of an electric furnace while the aluminum substrate specimen backface temperature rise with respect to time of exposure was continuously monitored and autographically recorded.

The most effective thermal coating developed was composed of an intumescent paint, No. 3 grade Vermiculite and 0.5 inch (1.27 cm) length graphite fiber in the respective ratios of 65.8 percent, 33.9 percent, and 0.03 percent by weight. This coating when applied at a thickness of 0.060 inch (0.15 cm) to an aluminum substrate and tested as described will insulate the substrate for a period of 6.8 minutes before a temperature of  $500^\circ\text{F}$  ( $260^\circ\text{C}$ ) is reached and for a period of 17.4 minutes before a temperature of  $800^\circ\text{F}$  ( $427^\circ\text{C}$ ) is reached.

Task II consisted of thermally characterizing 60 government furnished ceramic felts by exposing them to a thermal flux of  $15 \text{ BTU/ft}^2\text{-sec}$  ( $17 \text{ joules/cm}^2\text{-sec}$ ) by the same test method as described for Task I specimens. These specimens were bonded to aluminum substrates and the backface temperature rise with respect to time of exposure was also continuously monitored and autographically recorded.

The best coating system evaluated in Task I was used in conjunction with glass/honeycomb for prefabricated test panels for Task III. In this task, prefabricated thermal barrier sections were installed in the front bulkhead and floor sections of an A-4 aircraft cockpit on site at the Naval Weapons Center at China Lake, California. The effectiveness of this insulative concept will be evaluated during a fuel fire test in the latter part of 1976 by NWC personnel.

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## FOREWORD

This document is the final report prepared by Aeronutronic Division, Aeronutronic Ford under the Naval Weapons Center Contract N00123-75-C-0655 concerning thermal insulative materials for aircraft fire protection. The work was conducted at Aeronutronic Ford under J. L. Perry, Supervisor of the Composite and Graphite Section. The work was administered under the direction of the Naval Weapons Center, China Lake, California with Mr. W. T. Burt and Mr. A. San Miguel as project engineer. This report covers work conducted from December 1974 to April 1976.

## SUMMARY

An exploratory research and development program was performed for the purpose of providing an effective thermal barrier for aircraft and pilot protection in the event of aircraft fire.

Task I, which is the primary objective of the program, consisted of examining the effectiveness of expanding naturally occurring fillers (perlite and vermiculite) when used in combination with organic and inorganic matrix coating systems. Both filler systems expand and increase in volume up to 20 times when exposed to heat and liberate no toxic gases.

Thin coatings of these filler systems combined with various organic intumescent paints and inorganic matrix systems were developed and thermally evaluated. Test specimens were exposed to a frontface thermal flux environment of 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec) within the door opening of an electric furnace while the aluminum substrate specimen backface temperature rise with time of exposure was continuously monitored and autographically recorded. The most effective thermal coating developed was composed of an intumescent paint, No. 3 grade vermiculite and 1/2 inch (1.27 cm) length graphite fiber in the respective ratios of 65.8 percent, 33.9 percent, and 0.3 percent by weight. This coating when applied at a thickness of 0.060 inch (0.15 cm) to an aluminum substrate and tested as described will insulate the substrate for a period of 6.8 minutes before a temperature of 500°F (260°C) is reached and for a period of 17.4 minutes before a temperature of 800°F (427°C) is reached.

Task II consisted of thermally characterizing 60 government furnished ceramic felts by exposing them to a thermal flux of 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) by the same test method as described for the Task I specimens. These specimens were attached to aluminum substrates and the backface temperature rise with time of exposure was also continuously monitored and autographically recorded.

The best coating system evaluated in Task I was used in conjunction with glass/honeycomb for prefabricated test specimens for Task III. In this task, prefabricated thermal barrier sections were installed in the front bulkhead and floor sections of an A-4 aircraft cockpit on site at the Naval Weapons Center at China Lake, California. The effectiveness of this insulative concept will be evaluated during a fuel fire test in the latter part of 1976 by NWC personnel.

Task IV consisted of the application of a pyrex glass mosaic overlay to the plexiglas canopy of an A-4 aircraft. Squares of pyrex glass were bonded to the entire surface of the plexiglas canopy with a transparent silicone adhesive. An evaluation of the effectiveness of this overlay in increasing the heat resistance of the plexiglas during an actual fuel fire test environment will also be conducted by NWC personnel in the latter part of 1976.

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## SECTION 1

### INTRODUCTION

This program is concerned with the development and evaluation of thermal protective coatings and composites for use in aircraft and pilot compartment protection in the event of an aircraft fire. Carrier based aircraft, under conditions of a general shipboard fire beneath or around the wings and fuselage, are limited to a very short exposure time. Fuel tank rupture can occur in 40 seconds and pilot survivability, in the cockpit area, is on the order of 90 seconds. Fuel spillage and fuel spread exposes and endangers adjacent aircraft and initiates a chain reaction which can result in extensive loss of aircraft and personnel.

Fire fighting personnel and fire fighting techniques cannot effectively respond to this situation within the allowable exposure time. However, if this very short exposure time could be increased on the order of several minutes then the existing fire control measures would have sufficient time to either control the fire or remove the aircraft to an isolated area. It is the objective of this program to develop and evaluate promising potential thermal coating and thermal barrier concepts which offer such a time distinction from the existing 40 seconds to a goal of 5 minutes. Fire retardant paints and coatings are of two general types, intumescent and nonintumescent. The nonintumescent coatings are suitable for noncombustible surfaces only because of their much higher thermal conductivity properties and were not considered to be promising for this application. Intumescent coatings contain foaming agents which are decomposed by heat and when subjected to high temperatures they increase in volume and produce a highly effective insulating carbon foam. However, the resulting expanded mass is lacking in structural integrity and in addition the precursor resin matrix liberates considerable amounts of toxic gases. A viable approach to enhance the performance of intumescent coating systems is by the addition of expanding inorganic mineral fillers such as perlite and vermiculite.

Perlite is a naturally occurring glassy volcanic rock containing 2.0 percent to 5.0 percent chemically combined water. Perlite, when rapidly heated to its softening temperature, (1400°F to 2500°F) suddenly pops or expands (one to two seconds) and increases in volume up to 20 times its original size. The expansion is caused from the pressure generated by the chemically combined superheated water. The expansion is symmetrical about the geometrical center of the particle and produces an expanded particle consisting of a foam structure composed of microscopic sealed void cells. Due to this structure, expanded perlite is extremely light in weight (2 to 15 lbs/ft.<sup>3</sup>) and very low in thermal conductivity (0.25 to 0.50 BTU/hr/ft<sup>2</sup>/°F/in.). The low thermal conductivity is attributed to the discontinuous heat conduction paths of the cellular structure and the increased path length after expansion. Several potential advantages of perlite when used as an in-situ thermal protective material are: (a) the conversion of heat energy to mechanical energy by the expansion mechanism, (b) the cooling effect of the released water vapor, and (c) the low thermal conductivity of the expanded perlite.

The term vermiculite is given to a group of hydrous micas, usually alteration products of phlogopite or biotite micas, characterized by the ability, when heated above 150°C, to expand at right angles to the cleavage to a volume 6 to 20 times (average 16) that of the unexpanded mineral.

The property of expansion has been explained by at least two theories. The most generally accepted one is that the expansion is caused by the pressure of steam generated by heating the water of composition. This process is similar to that involved in the "popping" of perlite, and the product is somewhat similar except in one detail. The expansion is in one direction only at 90 degrees to the cleavage plane. The flake may increase from 10 to 30 times its original thickness. The second theory is that much of the expansion is due to warping of individual laminae because of unequal strains set up by steam pressure. This theory is used to account for the fact that expansion takes place even with very slow heating. In addition to the increase in volume and the development of the minute voids responsible for its insulating value, the vermiculite is altered by oxidation of its iron content. The addition of these inorganic fillers to intumescent matrices should produce a foamed structure with increased strength properties and should decrease the amount of toxic gases liberated during the expansion phenomena. This program consisted of the following four tasks. Task I, the primary task, was the development and evaluation of thin intumescent coatings containing fillers such as vermiculite and perlite. Task II consisted of testing and evaluating 60 Government furnished thermal resistant ceramic felts by the same thermal test evaluation method used for the Task I specimens. Task III was the installation of the most effective thermal coating concept evaluated in Task I in certain areas of an A-4 cockpit. The areas to be protected were the front bulkhead and floor sections of the cockpit and would utilize the coating in combination with a glass/phenolic honeycomb. Installation was to be performed at the Naval Weapon Center at China Lake, California. Task IV was concerned with the thermal protection of the plexiglas cockpit canopy during a fire environment. This task consisted of adhesively bonding pyrex glass squares in a mosaic fashion over the external portion of the plexiglas canopy.

## SECTION 2

### APPROACH

This section presents the approach to each of the following tasks.

#### 2.1 TASK I

This project involved the evaluation and development of an effective thermal barrier coating to be used for aircraft and pilot compartment protection.

##### 2.1.1 MATERIALS

A wide range of materials (listed in Appendix A) were chosen for testing and evaluation. The types of materials examined were expanding fillers, intumescent paints and flame resistant phenolic/silica combined with matrix systems such as epoxy's, vinyl plastisols, silicones, urethanes, and elastomeric solutions.

##### 2.1.2 TEST SPECIMEN AND TEST CHAMBER DESIGN

A K. H. Huppert muffle furnace was selected to supply the high temperatures required for testing; it is capable of 3000°F (1649°C). 6061 T6 aluminum 0.040 inch (0.102 cm) was selected as the substrate base for the test specimens. The opening of the muffle furnace is 3.5 x 3.5 inches (8.89 x 8.89 cm), so to allow the specimen to be inserted into the opening of the furnace the aluminum substrate was cut to 3.4 inch (8.64 cm) squares.

A 1.025 inch (2.604 cm) circular hole was punched out of the center of the aluminum substrate and a 0.85 inch (2.16 cm) slug was bonded into this hole with a ceramic bonding agent (Sauereisen cement) such that there would be 0.0875 inch (0.2222 cm) of the ceramic bonding agent between the aluminum plate and the aluminum slug (see Figure 1). This isolation of the plug minimizes the effects of any unequal heating contributed by the surrounding aluminum plate. One face of the aluminum substrate was completely coated with the material to be tested (see Figure 2).

A door (shown in Figure 3) was hinged on the muffle furnace in such a way that when the specimen was mounted on the door it could be closed against the furnace and the specimen would line up with the opening of the furnace.

##### 2.1.3 TEST METHOD

The specimens were individually mounted on the door described above and when closed were exposed to 13.5 BTU/ft<sup>2</sup>sec (15.3 joules/cm<sup>2</sup>sec). To detect the rise in temperature of the backface of the aluminum substrate, a chromel alumel thermocouple was held against the backface of the isolated plug through a small hole in the door by a spring loaded device which insured contact. An oscillograph was used to record the rise in temperature with respect to time.

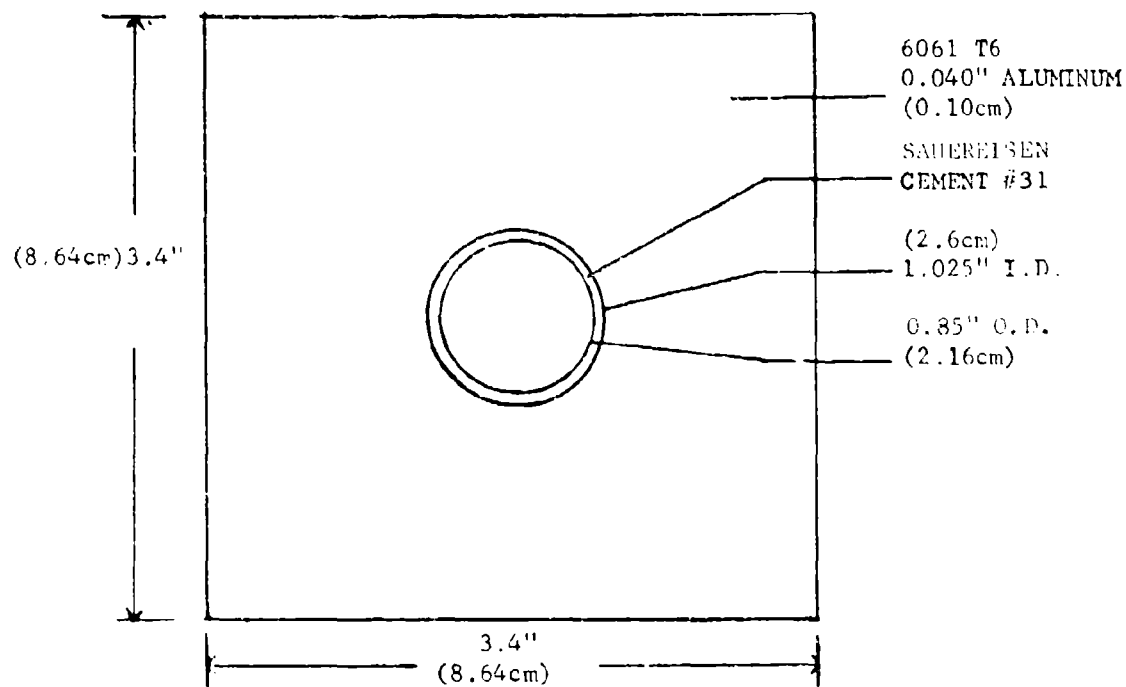


FIGURE 1. ALUMINUM SUBSTRATE

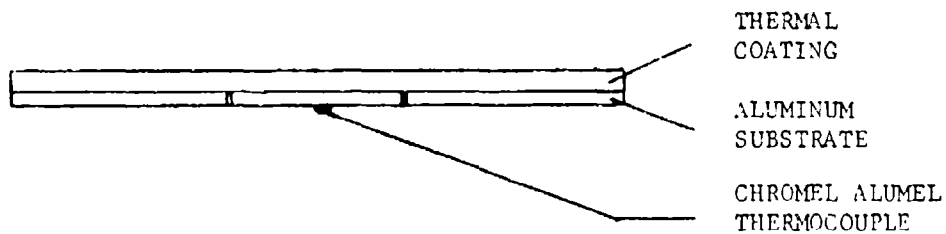


FIGURE 2. THERMAL COATING TEST SPECIMEN



FIGURE 3. DOOR HINGED TO MUFFLE FURNACE USED FOR MOUNTING TEST SPECIMENS

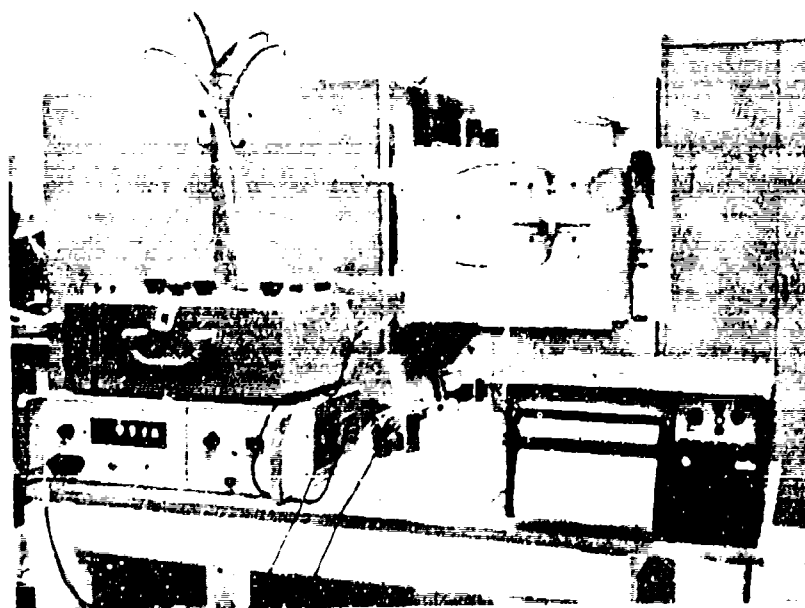


FIGURE 4. TESTING APPARATUS USED FOR RECORDING THERMAL RESPONSE

The oscillograph was calibrated with a battery potentiometer to be able to reduce the millivolt output signal of the thermocouple recorded on the strip chart to degrees Fahrenheit (or Celsius). This equipment can be seen in Figure 4. The furnace is in the background of Figure 4; the hoses leading to the door are used to supply water to the water jacket around the thermocouple, used only in cooling between runs to speed up the process of testing. A close-up of the thermocouple and water jacket is shown in Figure 5. The water jacket was used in conjunction with electric fans.

The backface of the aluminum substrate was allowed to reach 800°F (427°C) before being removed from the heat source.

## 2.2 TASK II

This task consisted of testing and evaluating 60 government furnished thermal resistant ceramic felts.

### 2.2.1 TEST SPECIMEN AND TEST CHAMBER DESIGN

The ceramic felts were cut to 3.4 inch (8.64 cm) squares and bonded to the same type of aluminum substrate used in Task I with Epibond 122 adhesive and 952 hardener. The same modified muffle furnace was used in this task as in Task I.

### 2.2.2 TEST METHOD

The test method used in Task II was the same as the test method used in Task I with one exception. The specimens were exposed to 15 BTU/ft<sup>2</sup>sec (17 joule/cm<sup>2</sup>sec) in this task where the specimens were exposed to 13.5 BTU/ft<sup>2</sup>sec (15.3 joules/cm<sup>2</sup>sec) in Task I.

## 2.3 TASK III

This task included taking the thermal barrier developed in Task I and incorporating it with phenolic glass honeycomb to produce a type of sandwich panel. The second part of this task was installing several sandwich panels in the cockpit of an A-4 jet.

## 2.4 TASK IV

This task consisted of mounting 2 x 2 x 0.25 inch (5.08 x 5.08 x 0.635 cm) pyrex glass section on the A-4 cockpit canopy assembly. This mosaic overlay was formed by bonding each pyrex square, piece by piece, to the plexiglas with a transparent silicone adhesive. A thin copper foil between each glass section and an overlay of safety wire attached to a brass peripheral strip was also installed.

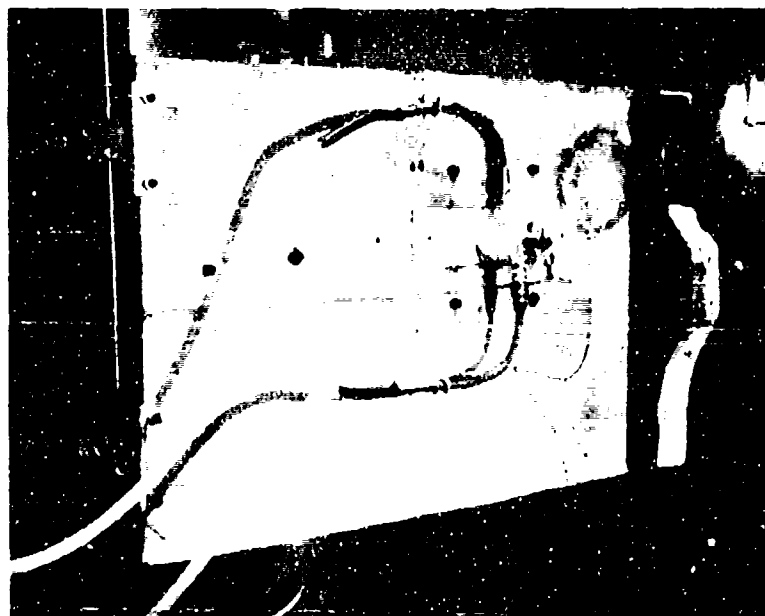


FIGURE 5. CLOSE UP OF WATER JACKET AND THERMOCOUPLE WIRE

## SECTION 3

### TECHNICAL DISCUSSION

#### 3.1 TASK I DEVELOPMENT OF AN EFFECTIVE THERMAL BARRIER COATING

One hundred and three test specimens were exposed to a thermal flux environment of  $13.5 \text{ BTU/ft}^2\text{-sec}$  ( $15.3 \text{ joules/cm}^2\text{-sec}$ ). Substrate backface temperature was recorded with respect to time for each specimen. A list of the different combinations of matrices and fillers plus the thickness of each specimen is in Appendix B.

A control specimen of Flamarest epoxy paint reached a  $500^\circ\text{F}$  ( $260^\circ\text{C}$ ) temperature within 3 minutes. The addition of Perlite to the Flamarest paint degraded the thermal characteristics by displaying a quicker time to  $500^\circ\text{F}$  ( $260^\circ\text{C}$ ). The Vermiculite filled specimens were all better than the unfilled Flamarest and resulted in  $500^\circ\text{F}$  ( $260^\circ\text{C}$ ) substrate temperature times of 4 to 4.5 minutes.

The use of a silicone elastomer also showed that vermiculite is more desirable as a filler than perlite. The time to  $500^\circ\text{F}$  with the perlite filler was within 30 seconds where the vermiculite filled elastomer was 2.5 minutes for the No. 2 vermiculite and within 2 minutes for the No. 4.

Sodium silicate was tested with aluminum hydroxide, perlite, vermiculite and borax filler systems. None of the systems offered the potential of an efficient thermal barrier but the best gain was again achieved with vermiculite.

Many systems were evaluated but none of them offered the potential of ALBI-107A. It was decided that ALBI-107A would be the matrix chosen for a more extensive evaluation.

##### 3.1.1 SELECTION OF FILLERS, PERCENTAGES OF FILLERS, AND COATING THICKNESS FOR OPTIMUM THERMAL CHARACTERISTICS

ALBI-107A was selected for its superior thermal insulative characteristics, both in the unaltered as received condition and after being mixed with various filler systems. In Figures 6 and 7 pictures of the pure ALBI-107A, initial coatings of 60 and 135 mils (0.15 and 0.34 cm), after frontface exposure to  $13.5 \text{ BTU/ft}^2\text{-sec}$  ( $15.3 \text{ joules/cm}^2\text{-sec}$ ) are shown. Displayed in Figures 8 and 9 are pictures of perlite No. 816 filled ALBI-107A and vermiculite No. 3 filled ALBI-107A specimens after being exposed to the same thermal flux mentioned above.

Grade B-25 and FT-102 glass bubbles were tested as fillers with ALBI-107A but neither of the two grades were found to be effective thermal barriers. They, in fact, reduced the thermal effectiveness of the matrix.

In order to establish a data base for comparative purposes, five specimens of unfilled ALBI-107A of increasing coating thickness were prepared. The effect of the coating thickness, 0.025 in. through 0.110 in. (0.064 cm through





FIGURE 6. SPECIMEN 35-1 - ALBI-107A MATRIX WITH NO FILLER.  
INITIAL THICKNESS WAS 60 MILS (0.15 CM)



FIGURE 7. SPECIMEN 35-7 - ALBI-107A MATRIX WITH NO FILLER.  
INITIAL COATING THICKNESS WAS 135 MILS (0.34 CM)



FIGURE 8. SPECIMEN 46-1 - ALBI-107A MATRIX WITH 34 PERCENT NO. 816 PERLITE FILLER. INITIAL COATING THICKNESS WAS 120 MILS (0.30 CM)



FIGURE 9. SPECIMEN 41-1 - ALBI-107A MATRIX WITH 34 PERCENT VERMICULITE FILLER. INITIAL COATING THICKNESS WAS 110 MILS (0.28 CM)

0.279 cm) is shown in Figure 10. The thickest coating specimen, 0.120 in. (0.305 cm), is not plotted because the thermal response for this specimen was between specimens of 0.070 in. (0.178 cm) and 0.110 in. (0.279 cm). The data show, as one would predict, that the thermal effectiveness is related to the coating thickness, but there is a maximum thickness to be used.

Presented in Figure 11 are the results obtained with four particle size grades of perlite, grade 816 the coarsest particle and grade 4500 the smallest particle, at a 34 percent filler concentration. The perlite specimens exhibit a definite trend for the thermal efficiency to decrease with the particle size of the perlite. Presented in Figure 12 are the results of different size particles of perlite at a 66 percent filler concentration, again the specimens exhibit the same tendency for a decrease in thermal protection with a decrease in particle size. Comparing Figures 11 and 12 you can see that a filler loading level of 34 percent is considerably more effective than 66 percent.

Presented in Figure 13 are the results of various particle size grades of vermiculite at 34 percent filler concentration. Grade No. 1 vermiculite is the largest and Grade No. 5 vermiculite is the smallest particle. Again there is the tendency for a decreased thermal protection with decreased particle size except specimen 41-1 with No. 3 particle size appears to exhibit better thermal protection than specimen 37-2 with No. 2 particle size.

Figure 14 shows the effects of two filler loading levels formulated with vermiculite No. 3 and two different lengths of carbon fiber which is at the concentration of 1 percent of the filler. The 34 percent filler concentration yields the best thermal properties and the addition of fibrous reinforcement appears to enhance the thermal insulative properties. The 3 inch (7.6 cm) and 0.5 inch (1.27 cm) long carbon fibers have nearly equivalent results, but in considering the difficulties in mixing the fire retardant, the 0.5 inch (1.27 cm) carbon fiber is superior. The carbon fiber was compared to blue asbestos fiber in a specimen test and the carbon fiber appears to be better than the asbestos when present with the vermiculite filler. A picture of the result of testing specimen No. 50-1 with 66 percent ALBI-107A and 34 percent filler (vermiculite No. 3 and 3 in. (7.6 cm) carbon fiber 1 percent of filler) is presented in Figure 15.

The results of 47 specimen tests are presented in Appendix C. Specimen 46-1 which was 34 percent 816 perlite filler and 66 percent ALBI-107A matrix had a time to 800°F of 20 minutes which is the best result obtained. This same combination was tested again and the time to 800°F was much lower. This inability to obtain repeatability may be linked to the large particle size of the filler.

### 3.2 TASK II

Each of the specimens, supplied to Aeronutronic Ford by NWC, China Lake, California, were cut to 3.4 inch (8.64 cm) squares and bonded to aluminum plates. The aluminum substrate were prepared in the same way as described in Task I and the same procedure and apparatus were used in testing the specimens with the exception that the heat flux was 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) instead of 13.5 BTU/ft<sup>2</sup>-sec (15.3 joules/cm<sup>2</sup>-sec) as used in Task I.

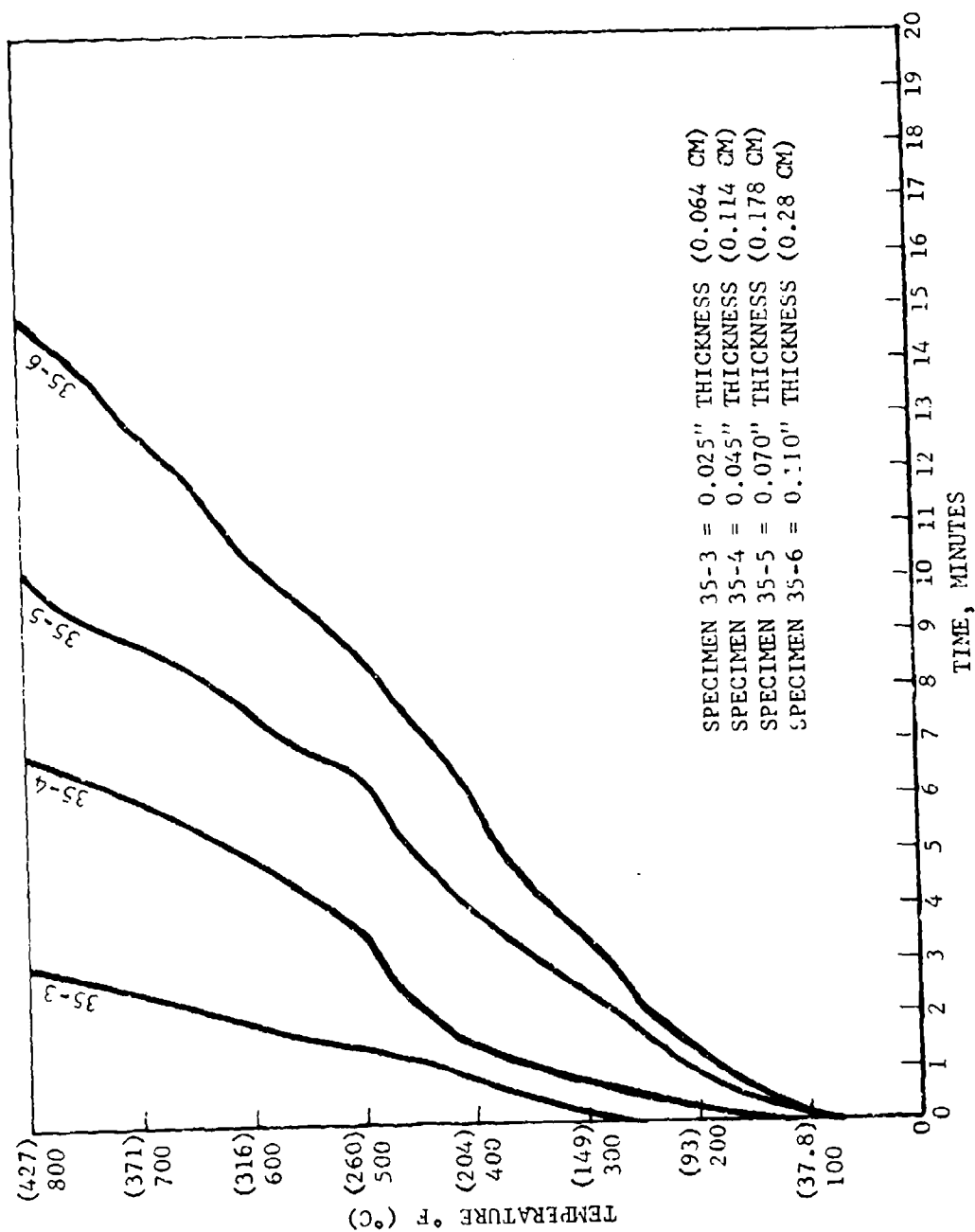


FIGURE 10. BACKFACE TEMPERATURE RISE FOR VARYING COATING THICKNESSES OF ALBI-107A EXPOSED TO 2000°F FRONTFACE TEMPERATURE

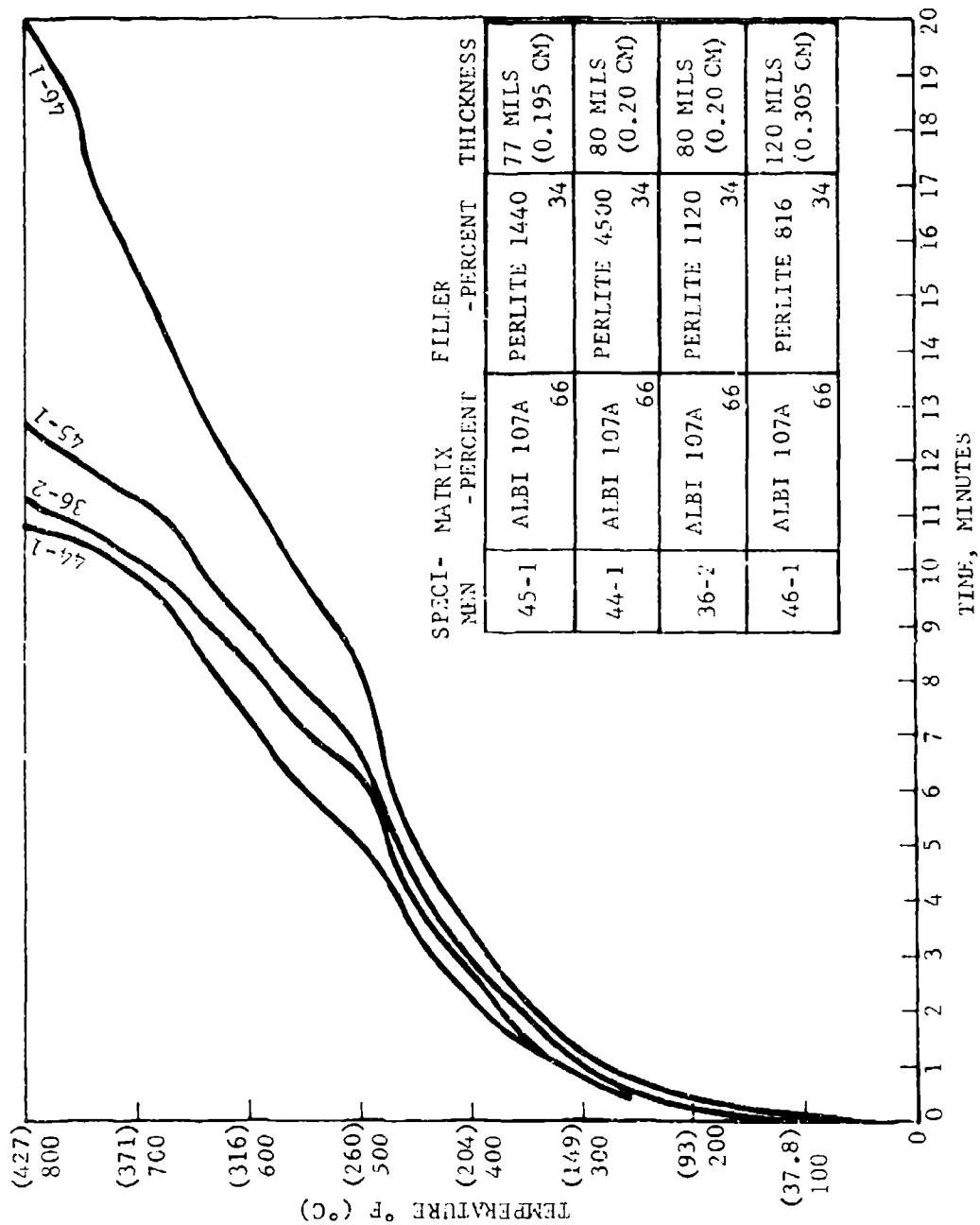


FIGURE 11. BACKFACE TEMPERATURE RISE FOR VARYING SIZES OF PERLITE (816 LARGEST)

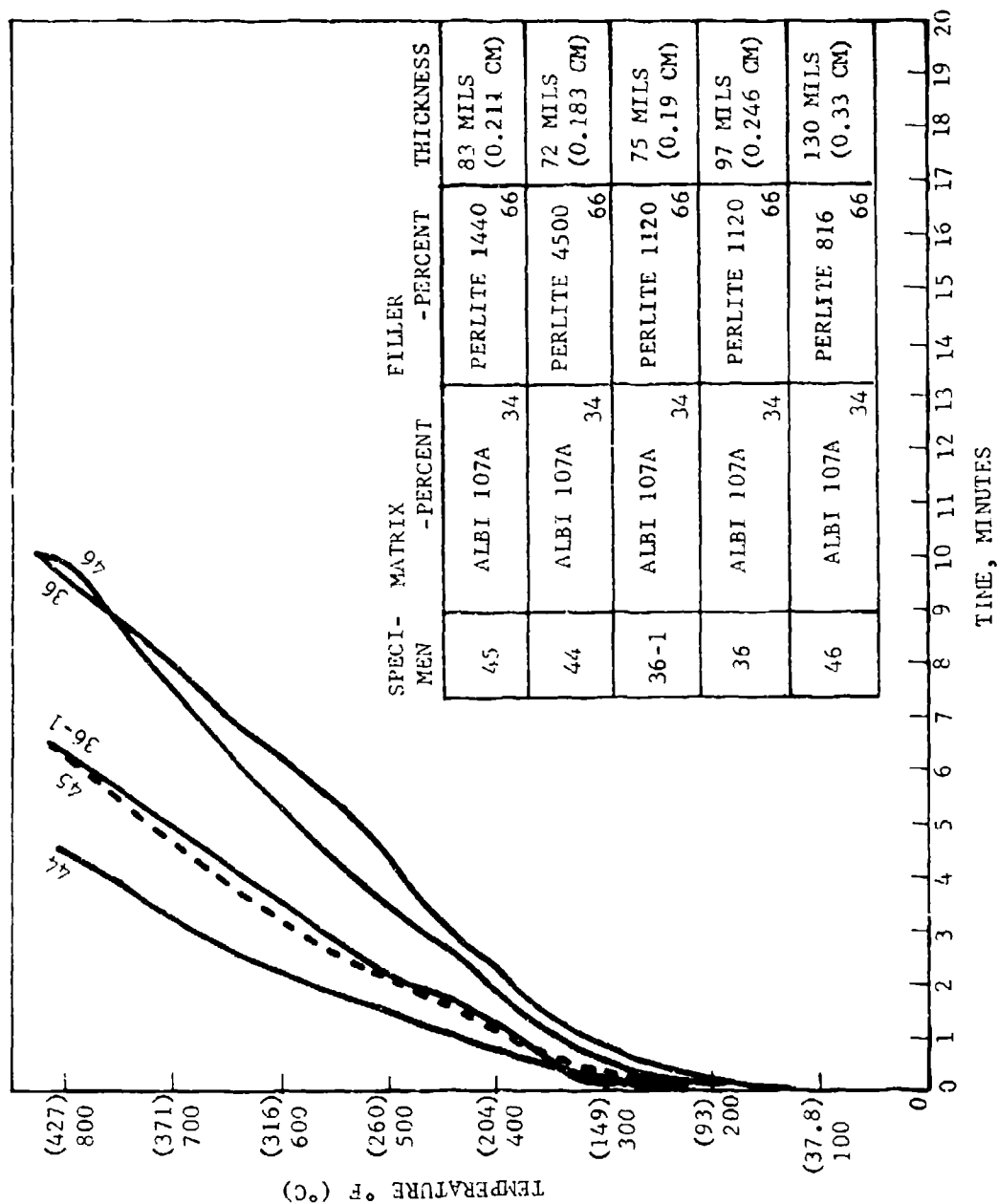


FIGURE 12. BACKFACE TEMPERATURE RISE FOR VARYING PARTICLE SIZE OF PERLITE  
AT THE CONCENTRATION OF 66 PERCENT

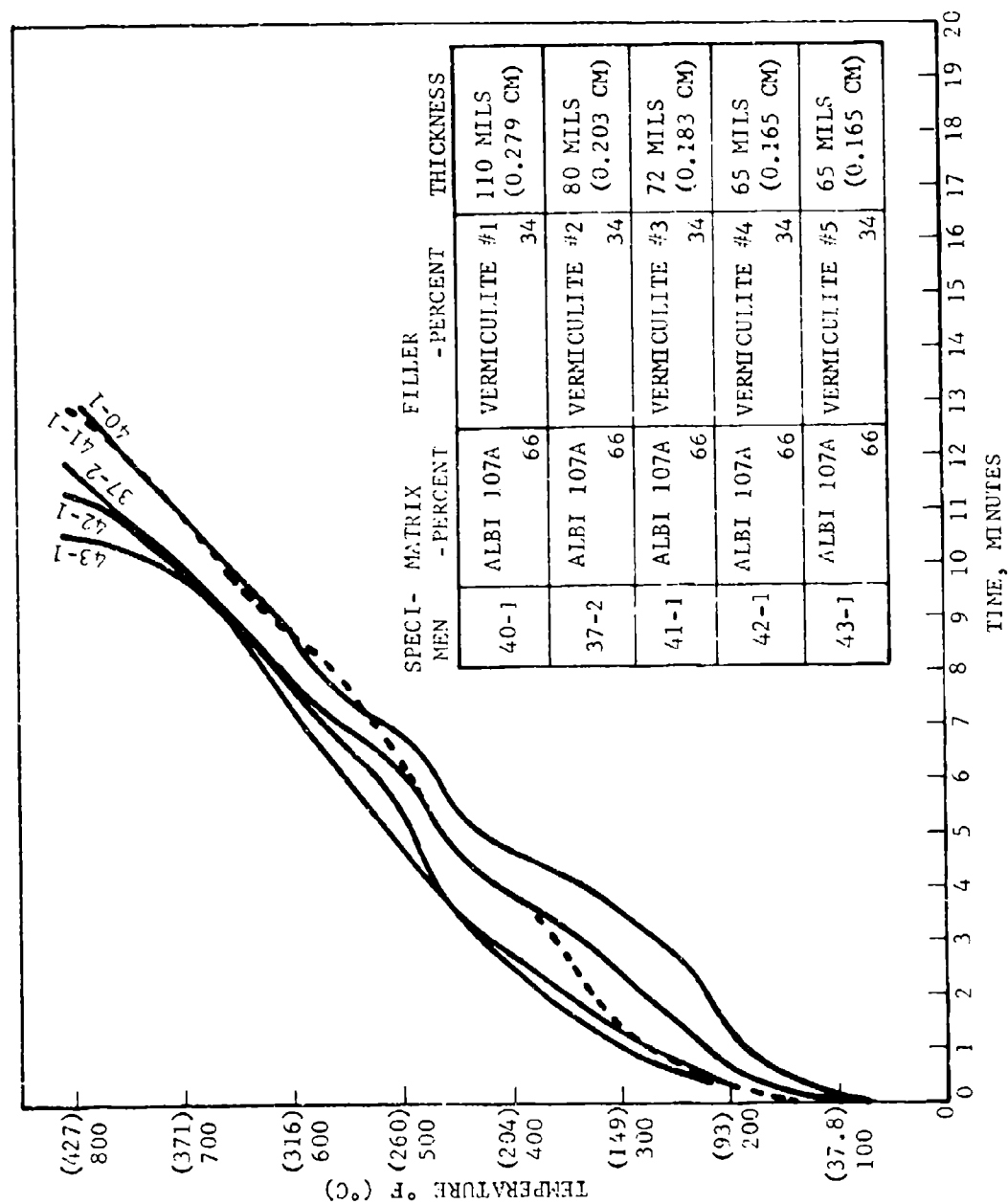


FIGURE 13. BACKFACE TEMPERATURE RISE OF VARYING PARTICLE SIZE OF VERMICULITE (#5 IS THE SMALLEST)

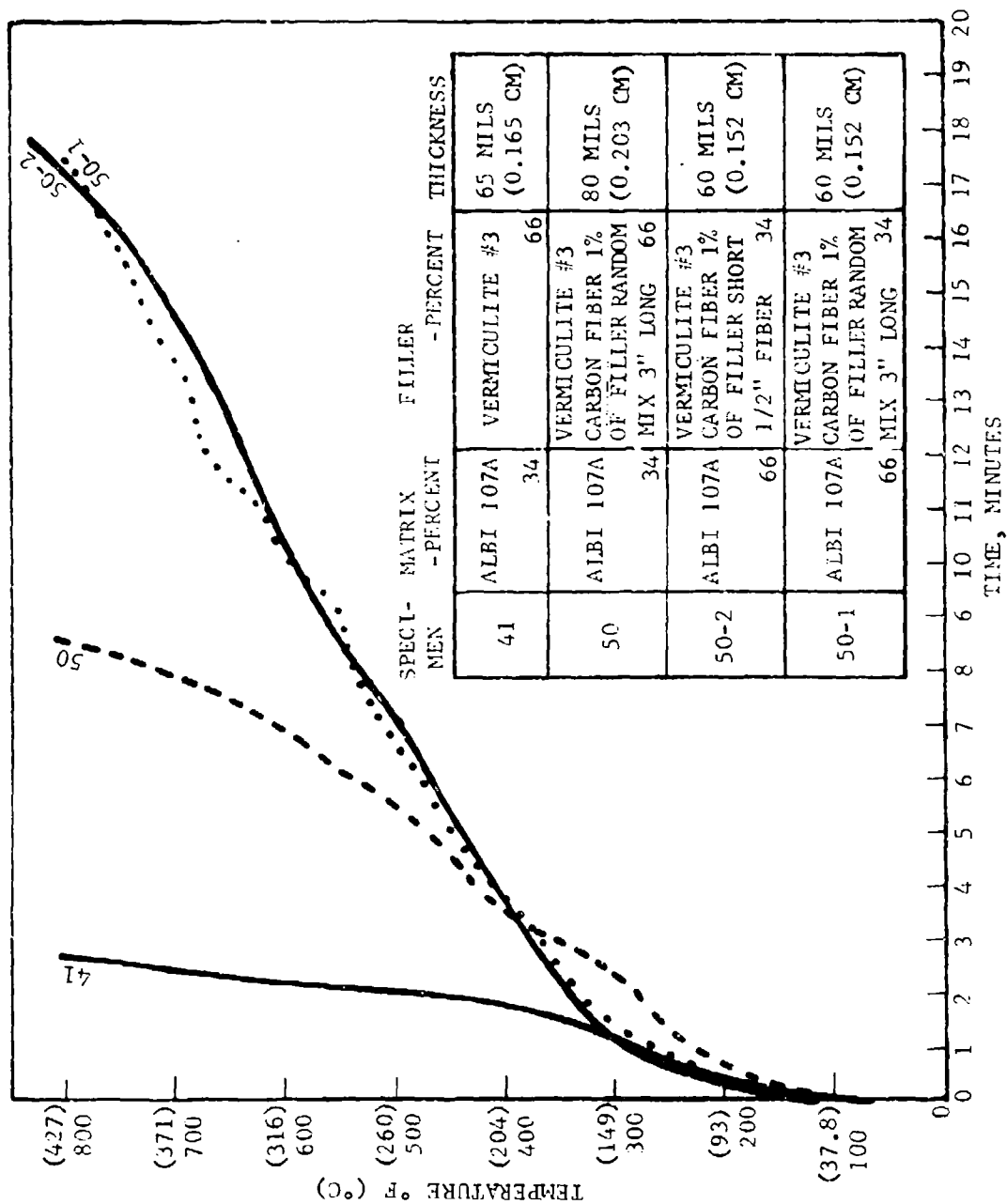


FIGURE 14. BACKFACE TEMPERATURE RISE WITH AND WITHOUT #3 VERMICULITE FILLER  
AT DIFFERENT CONCENTRATION, WITH TWO LENGTHS OF CARBON FIBER





FIGURE 15. SPECIMEN 50-1 - ALBI-107A WITH 34 PERCENT #3 VERMICULITE AND 3 INCH (7.6 CM) CARBON FIBER FILLER. CARBON FIBER IS 1 PERCENT OF THE FILLER. INITIAL COATING THICKNESS WAS 60 MILS (0.152 CM)

The thermal response of each specimen was recorded and compiled (see Appendix D) and the specimens were divided into six categories according to their characteristic rise in temperature. A list of the different categories can be seen in Table 1.

Characteristics typical of type A are: a rapid rise in temperature, after exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) for 1 minute, to around 350°F (177°C) which is attained shortly after 2 minutes. Then the rise in temperature continues but at a slower rate. The average time to 800°F (427°C) is around 15 minutes.

Type A-1 characteristics are similar to type A in that they have the same rapid initial rise in temperature but type A-1 normally has a slightly increased rate of initial rise in temperature and reaches a higher point at which the rate of rise in temperature decreases. The average time to 800°F (427°C) is 10 minutes for type A-1.

Type A-1 can also be split into two categories A-1x and A-1z. They differ in the temperature at 1 minute. The average temperature of A-1x at 1 minute is 175°F (79°C) where A-1z has an average temperature of 250°F (121°C).

Type A-2 also has a rapid initial increase in temperature but it starts around 30 seconds of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) and at 1 minute the average temperature is 340°F (171°C). The average time to 800°F (427°C) is 9.5 minutes.

Type C doesn't have the rapid rise in temperature as in the above categories. It has a relatively steady increase in temperature with the exception of a leveling off or even a decrease in temperature around 2 to 3 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec) in some specimens. The average time to 800°F (427°C) is 13 minutes.

Type C-1 also has a steady increase in temperature but has an outstanding average time of 27 minutes to 800°F (427°C) with one specimen going to 31 minutes, which was the only non-ceramic felt specimen. Graphs representative of each type are shown in Figures 16 and 17.

There are five specimens that have to be mentioned separately because they do not fall into these categories. T-119B and C showed a very rapid rise in temperature and had a time of about 4 minutes to 800°F (427°C), which was probably due to the fact that they were very thin. T-3 can almost be classified as type A-1 but the rapid increase in temperature did not start until after 2 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). T-107 and T-105 had a time to 800°F (427°C) of type A and the rapid increase in temperature similar to type A-1z.

Not all specimens displayed an always increasing rise in temperature. Some held a constant or almost constant temperature for a short while, usually from 30 seconds to 1 minute, starting anytime from 30 seconds to 3 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). Examples of this are T-2, T-4, T-5, T-6, T-8, T-10, and T-11 which displayed the leveling off period at

TABLE 1. LIST OF SPECIMENS IN EACH CATEGORY

<u>Type A</u>	<u>Type A-1x</u>	<u>Type A-1z</u>	<u>Type A-2</u>
T-1	T-2	T-9	T-26
T-13	T-4	T-24	T-27
T-15	T-5	T-51A	T-106
T-17	T-6	T-52A	
T-18	T-7	T-52B	
T-19	T-8	T-53	
T-20	T-10	T-54	
T-22	T-11	T-104	
T-23	T-14	T-121	
T-108	T-21	T-122B	
T-109	T-51B		
T-110	T-112		
T-111	T-120		
T-113	T-125		
T-114	T-S-2		
T-122A			
T-124		<u>Type C</u>	<u>Type C-1</u>
T-126		T-129B	T-116
T-127		T-130A	T-118
T-128A		T-130B	T-129A
T-128B		T-131A	
T-S-1		T-131B	

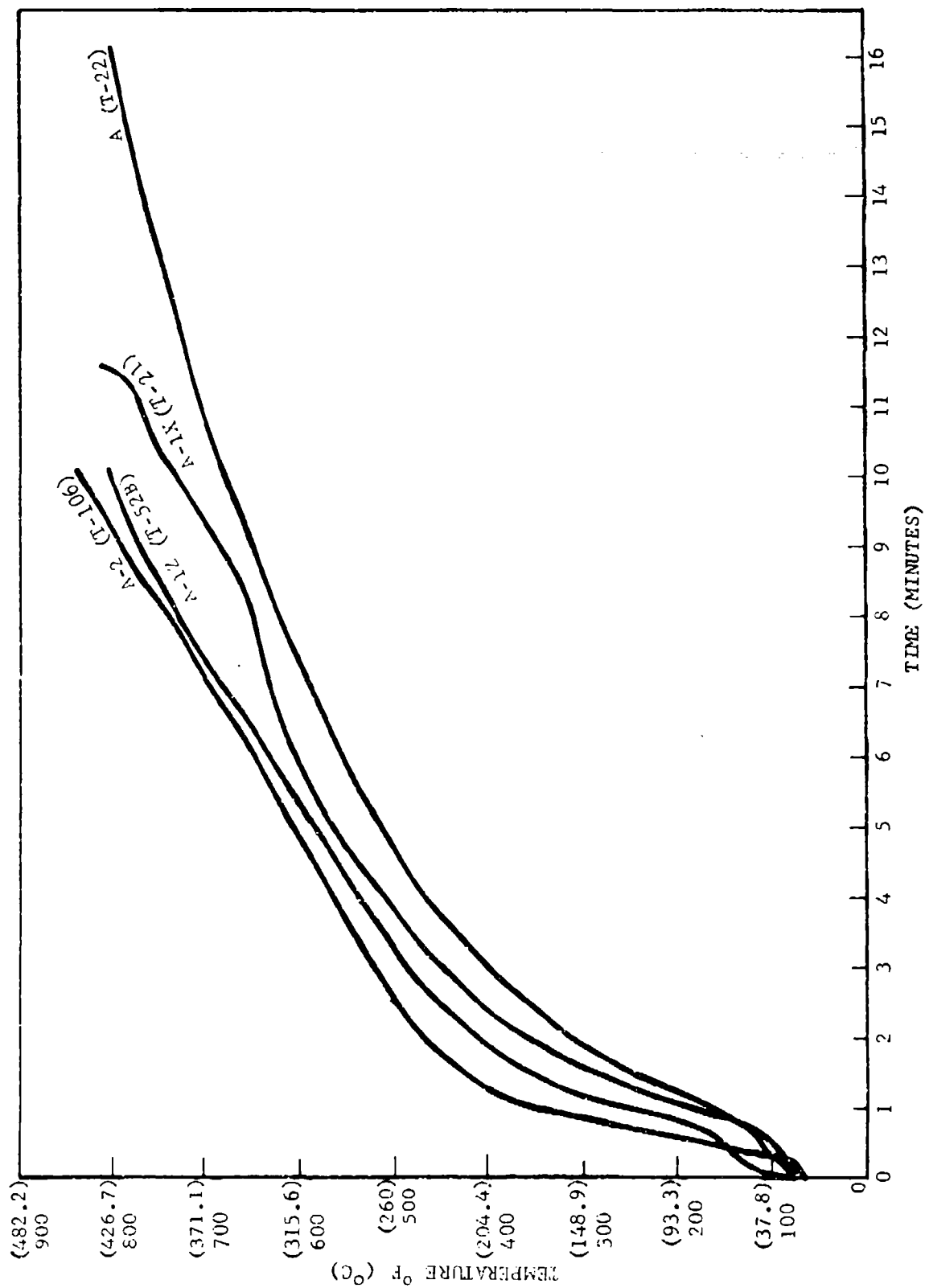


FIGURE 16. THERMAL RESPONSE REPRESENTATIVE OF TYPES A, A-1X, A-1Z AND A-2

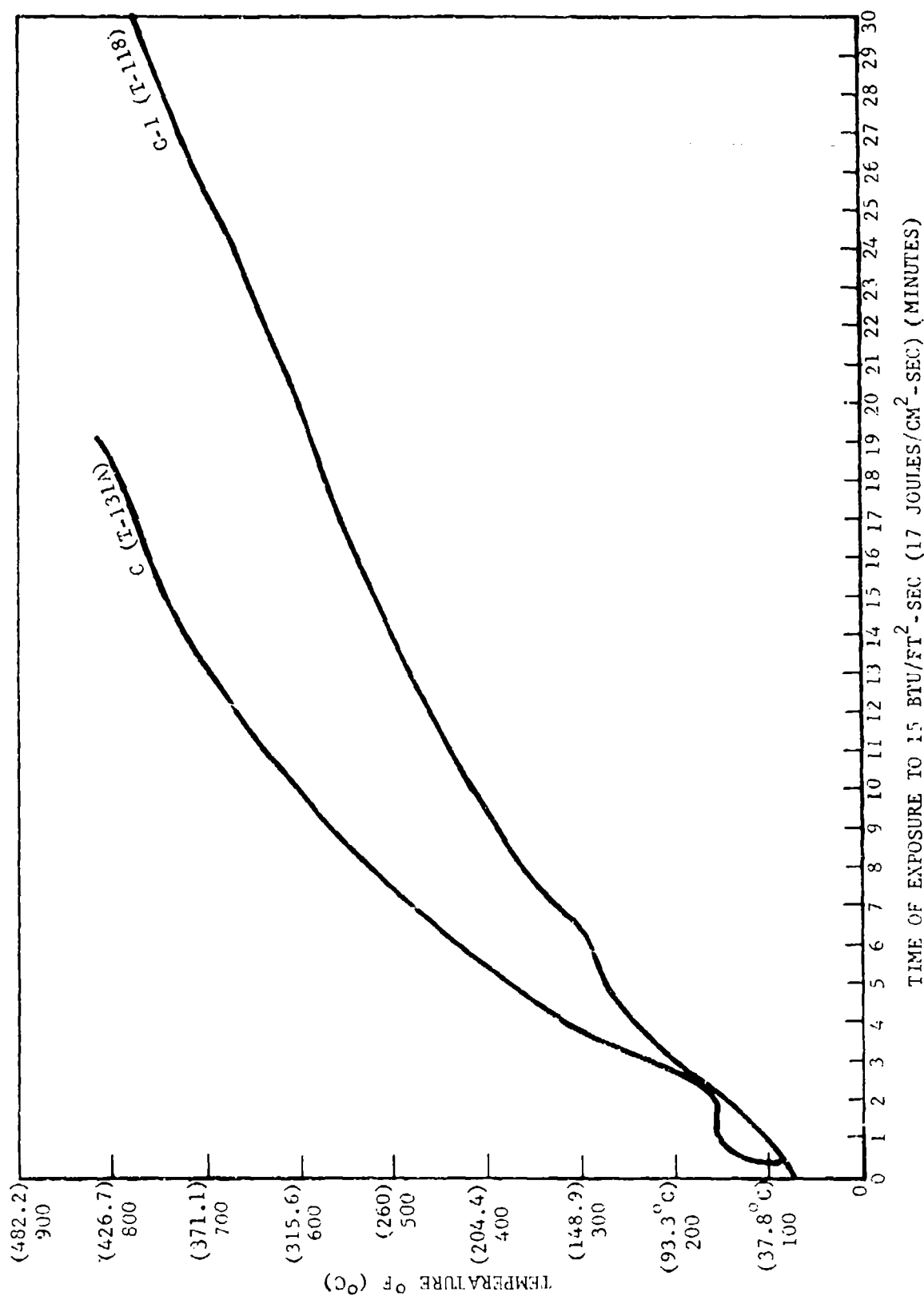


FIGURE 17. THERMAL RESPONSE REPRESENTATIVE OF TYPES C AND C-1

30 seconds to 1 minute of exposure to 15 BTU/ft<sup>2</sup>-sec (17 joules/cm<sup>2</sup>-sec). T-3 and T-129B both displayed a leveling off at 1 to 2 minutes of exposure to the heat source, T-130B (2 to 3 minutes) and T-129A (3 to 4 minutes). A graph is shown in Figure 17 of T-131A demonstrating this phenomenon.

Other specimens displayed a drop in temperature. Examples of this are T-7 and T-14 at 30 seconds to 1 minute of exposure to the heat source and T-131A at 1 to 2 minutes of exposure to the heat source.

All specimens that displayed a leveling or drop in temperature did so before reaching 200°F (93°C) with the exception of one. T-129A did display a leveling off period at 3 to 4 minutes of exposure to 15 BTU/ft<sup>2</sup>-sec and 172°F (78°C) but also displayed a large drop in temperature after 14 minutes of exposure to the heat source at almost 600°F (315°C). A graph of T-129A is shown in Figure 18.

This phenomenon could be due to the felt coating flowing off of the felt and carrying the heat away from it.

Pictures of the six separate categories and uncategorized specimens are shown in Figures 19, 20, and 21. Identification diagrams are presented in Figures 22 and 23 to identify the specimens in Figures 19, 20, and 21.

A list of specimens including specimen number, date tested, thickness, and surface weights of the thermal resistant ceramic felts are in Appendix D. A table for the aluminum control runs is also in Appendix D.

### 3.3 TASK III

#### 3.3.1 FIRE PROTECTION OF PILOT COMPARTMENT

**3.3.1.1 Fabrication of the Fire Barrier.** The fire retardant material was mixed together in the following proportions: 33.9 percent No. 3 vermiculite, 65.8 percent ALBI-107A, and 0.3 percent high tensile strength graphite fiber 1/2 inch (1.27 cm) long. All percentages are by weight. Six sheets, 24.25 by 19 inches (61.60 by 48.26 cm), were made with 1/2 inch (1.27 cm) thick, 3/16 inch (0.48 cm) cell size, 5.5 lbs/ft<sup>3</sup> (88.1 kg/m<sup>3</sup>) glass/phenolic honeycomb set into the fire retardant material.

The sheets were prepared by placing a sheet of nylon film over an aluminum plate, then a layer of silicone impregnated fiber glass cloth (used for release) was placed over the nylon. The silicone impregnated fiber glass cloth was coated with a thin layer of ALBI-107A and allowed to dry to resist further absorption when the fire retardant mixture was applied.

A total of 1044g of the fire retardant was mixed and poured onto the release cloth and spread to an area approximately 24 x 19 inches (61 x 48 cm) which resulted in a thickness of about 0.080 inch (0.20 cm). The phenolic honeycomb was then placed on the fire retardant mixture. To push the honeycomb into the fire retardant mixture a press with a force of 20,000 pounds (88,964 newtons), which is approximately 45 psi (310,264 pascal), was used. When ALBI-107A had cured the release cloth was peeled off and the excess material was trimmed off.

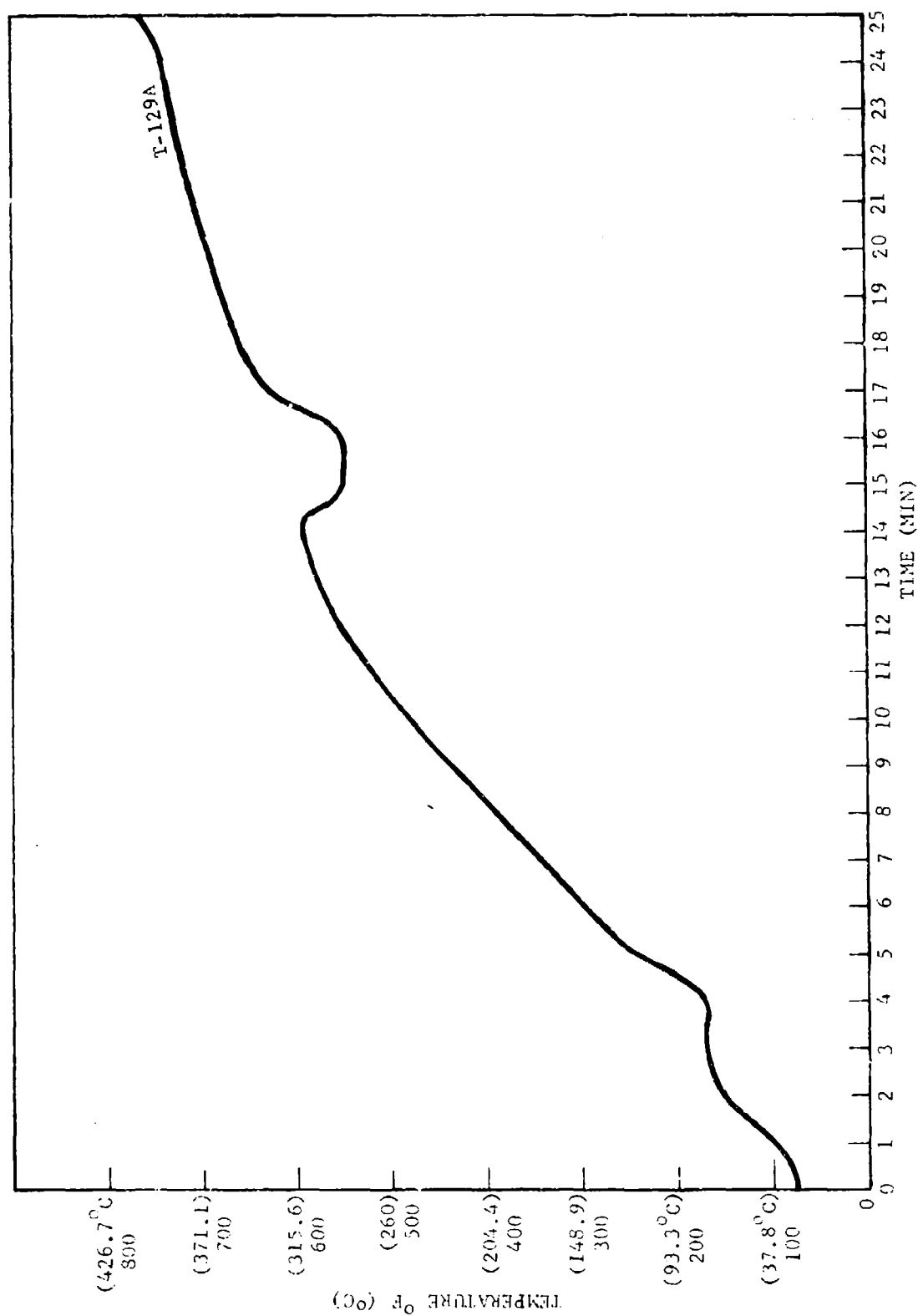


FIGURE 18. THERMAL RESPONSE OF SPECIMEN T-129A DISPLAYING A LARGE DROP IN TEMPERATURE AFTER 14 MINUTES

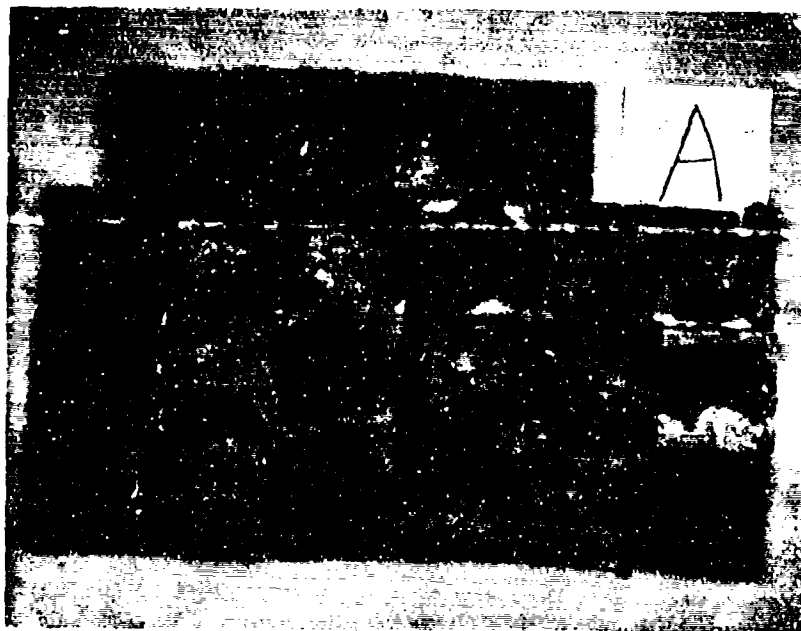


FIGURE 19. TYPE A SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC  
(17 JOULES/CM<sup>2</sup>-SEC)

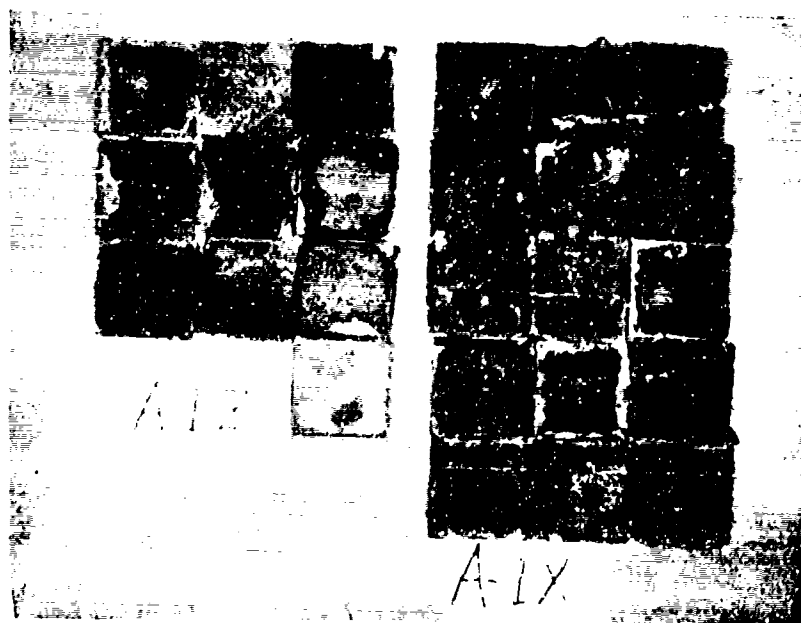


FIGURE 20. TYPE A-1 X AND Z SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC  
(17 JOULES/CM<sup>2</sup>-SEC)



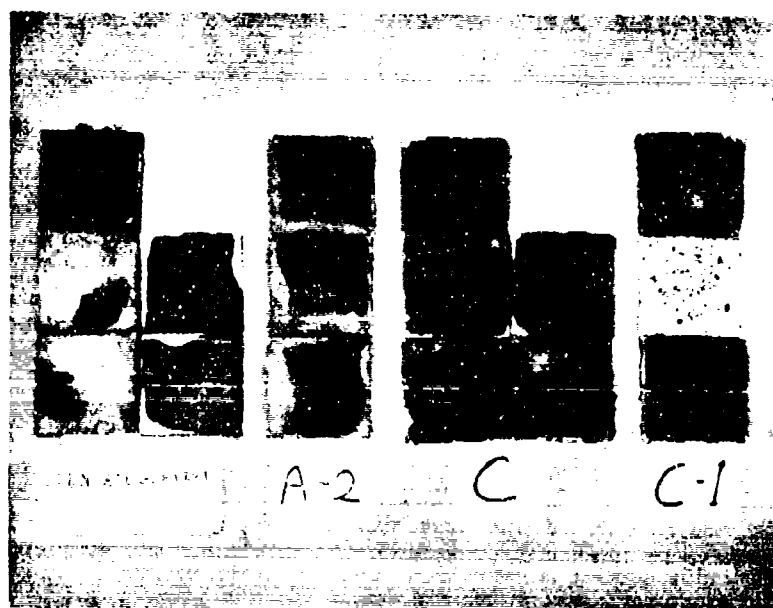


FIGURE 21. TYPES A-2, C, AND C-1 AND FIVE UNCATEGORIZED SPECIMENS AFTER EXPOSURE TO 15 BTU/FT<sup>2</sup>-SEC (17 JOULES/CM<sup>2</sup>-SEC)

TYPE A

<table><tr><td>T-127</td><td>T-128A</td><td>T-128B</td><td>T-S-1</td></tr></table>						T-127	T-128A	T-128B	T-S-1
T-127	T-128A	T-128B	T-S-1						
T-111	T-113	T-114	T-122A	T-124	T-126				
T-20	T-22	T-23	T-108	T-109	T-110				
T-1	T-13	T-15	T-17	T-18	T-19				

TYPE A-1X

TYPE A-1Z

T-24	T-9	T-52B
T-51A	T-53	T-121
T-52A	T-54	T-122B
		T-104

T-2	T-8	T-51B
T-4	T-10	T-112
T-5	T-11	T-120
T-6	T-14	T-125
T-7	T-21	T-S-2

FIGURE 22. IDENTIFICATION DIAGRAMS FOR FIGURES 19 AND 20

UNCATEGORIZED

T-3	
T-105	T-119B
T-107	T-119C

A-2

T-26
T-27
T-106

C

T-129B	
T-130A	T-131A
T-130B	T-131B

C-1

T-116
T-118
T-129A

FIGURE 23. IDENTIFICATION DIAGRAMS FOR FIGURE 21

Six sheets, 24 x 19 inches (61 x 48 cm), of fire retardant material were also made without the phenolic honeycomb using the same procedure described above.

3.3.3.2 Installation of the Fire Barrier into the A-4 Jet Pilot Compartment. Installation of the prefabricated fire retardant material was done on site at NWC, China Lake, California. To accomplish this, several of the pilot compartment components had to be removed such as the seat, side plates, foot pedals, partial disassembly of the control stick, some hydraulic lines, electrical boxes not fully identified, etc.

Clean up involved removal of the insulation pads and of the adhesive plus paint and primer, in some places, with rotary wire brushes and a drill motor. In some inaccessible areas, MEK and a scraper were used.

Cardboard templates were cut out and fitted into place before the fire retardant material was cut into sections. The sections were bonded with 122 adhesive and 952 catalyst. A total area of approximately 1400 square inches (9,032 square cm) was covered resulting in a weight gain of 3361g of fire retardant with honeycomb, 135g fire retardant without honeycomb, 950g 122 adhesive, and 700g wet fire retardant for patching, which is a total of approximately 5,146g.

The area covered included the entire floor area except for the center hump in the forward cockpit area.

The forward wall sections were covered within the area approximately 14 inches (35.6 cm) up from the floor and 13 to 15 inches (33 to 38 cm) back from the front bulkhead. Portions of the front bulkhead were also covered within the area 6 inches (15.2 cm) in from the walls, 14 inches (35.6 cm) up from the floor (left side), and 8 to 11 inches (20.3 to 27.9 cm) up from the floor (right side).

Some sections had to be cut into two or three sections to be fitted into place since the material does not bend very much. Figure 24 presents an exploded diagram of the sections installed in the cockpit of the A-4 jet. To fill in areas which were not covered because of inaccessibility or cracks between sections, a wet fire retardant mixture was mixed and used as putty would be used.

The project was finished by mounting a tent over the cockpit to protect the fire barrier from the elements since there was no canopy to keep the rain and dirt out.

#### 3.4 TASK IV

##### 3.4.1 PROCEDURE OF MOUNTING THE A-4 COCKPIT CANOPY ASSEMBLY OVERLAY

The plexiglas of the canopy was prepared by cleaning with soap and water then with ethyl alcohol. 2 by 2 inch (5.08 x 5.08 cm) squares, 0.125 inch (0.32 cm) thick were bonded to the plexiglas at five points, one in each corner and one in the center of each square, with RTV 108 silicone rubber made by G.E. RTV 108 was chosen for its bonding, translucent and heat resistant properties.

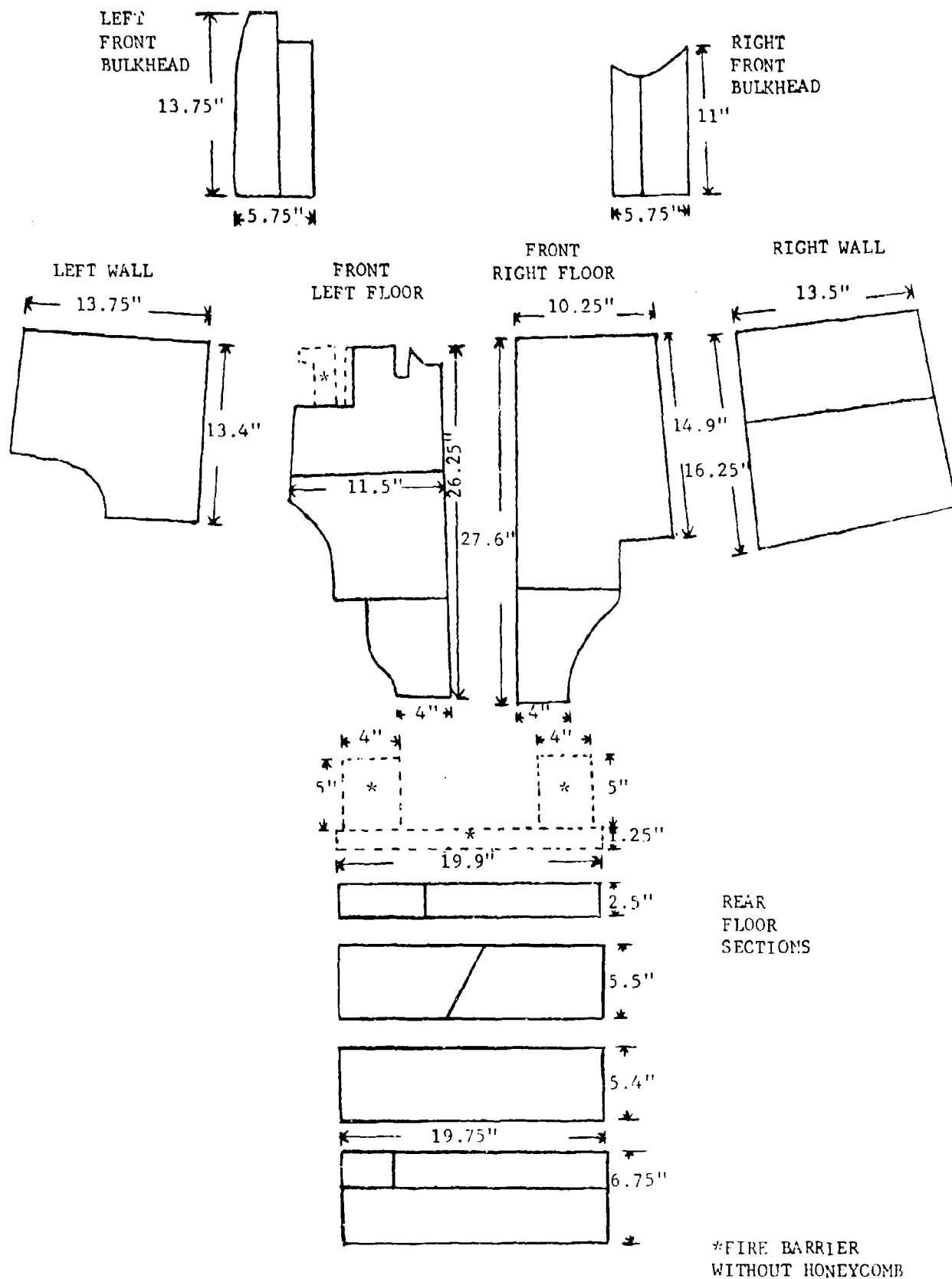


FIGURE 24. EXPLODED DIAGRAM OF FIRE BARRIER SECTIONS IN A-4 COCKPIT

In bonding the pyrex squares to the plexiglas, a minimum gap of 0.030 inch (0.076 cm) was maintained between each square to allow for thermal expansion of the pyrex. Larger gaps resulted in some places because the curvature of the plexiglas prevented each square from completely lining up with the squares on each side.

A brass rod 1 inch (2.54 cm) wide and 1/4 inch (0.635 cm) thick was mounted around the plexiglas and held in place by some of the bolts that hold the plexiglas in place. Holes were drilled in the brass rod and threaded for screws to hold the safety wire in place. The surrounding brass rod can be seen in Figure 25.

When the brass rod, pyrex squares and cut pyrex squares, which were made to fill in the area between the brass rod and the full squares, were in place 0.002 inch (0.005 cm) copper strips, cut to the thickness of the pyrex, were placed in the gaps between the pyrex squares. In Figure 26 it can be seen that the spaces between the pyrex squares running from the front of the overlay to the rear are all in line, so a copper strip was cut to size and to the curvature of the plexiglas from the brass rod in front, to the brass rod in the rear for each row of gaps running lengthwise. For the gaps between the squares running from one side to the other 2 inch (5.08 cm) copper strips were used.

The procedure of putting the copper strips in place is as follows: first, a small bead of RTV 108 silicone rubber was placed in the gap and the copper strip was set in place. Then another bead of RTV 108 was run along the gap trying to partially fill it. This was accomplished by the use of a Semco air gun with a small opening. When the silicone rubber had fully cured, the excess was cut off with a razor blade. The entire overlay was sealed except for openings left in the rear to allow for escaping air.

The final step was to install 0.015 inch (0.038 cm) stainless steel safety wire. This was accomplished by attaching the wire to the screws provided on the brass strip (shown in Figure 25). One wire was strung for each row of pyrex squares running lengthwise and from one side to the other, shown in Figure 26. At each intersection of wire, one wire was looped around the other to hold them in place. As a final touch the brass strip was cleaned and coated with a clear polyurethane.

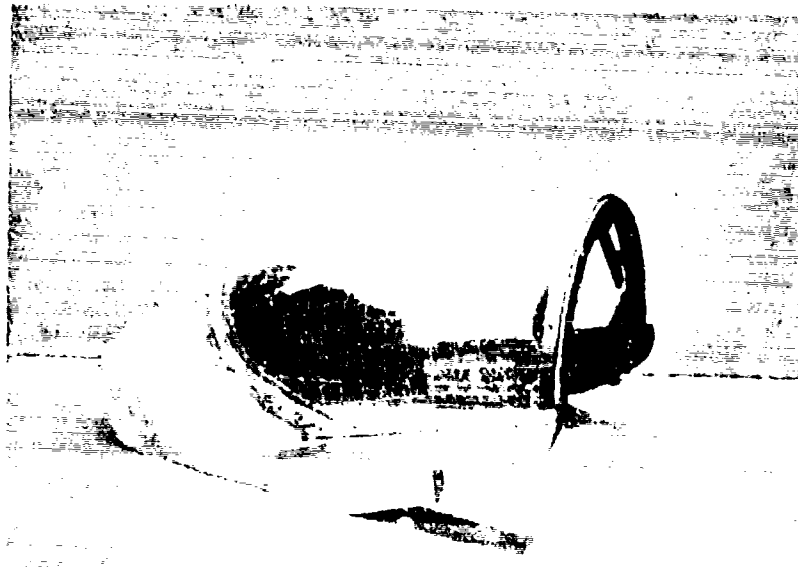


FIGURE 25. A-4 JET COCKPIT CANOPY ASSEMBLY



FIGURE 26. CLOSE UP OF THE MOSAIC OVERLAY

## SECTION 4

### CONCLUSIONS

#### 4.1 DEVELOPMENT OF AN EFFECTIVE THERMAL BARRIER COATING

The most efficient matrix system evaluated in this program was a solvent based modified vinyl coating identified as ALBI-107A. It is an organic intumescent coating which reacts to heat at 300°F (150°C) by foaming into a thick cellular insulation blanket and when exposed to test temperatures of 2000°F (1093°C) yields an insulative carbon foam. The best filler of the materials tested was unexpanded vermiculite, which is an inorganic intumescent mineral classified as a hydrous mica. Grade No. 3 vermiculite was found to be the most effective particle size when combined with ALBI-107A and the optimum matrix-filler proportion was 66 percent ALBI-107A and 34 percent vermiculite grade No. 3. The addition of a small amount of carbon fibrous reinforcement appears to further enhance the thermal protection.

Based upon testing conducted during this program, the best formulation is 65.84 percent ALBI-107A, 33.86 percent No. 3 vermiculite, and 0.03 percent 0.5 inch (1.27 cm) length high tensile strength carbon fiber. A 0.060 inch (0.15 cm) coating thickness of this formula on an aluminum substrate will protect the substrate 6.3 minutes to 500°F (260°C) and 17.4 minutes to 300°F (427°C) when exposed to 2000°F (1093°C).

This thermal barrier coating possesses good adhesion to an aluminum substrate and can be applied directly to the substrate or can be fabricated as a precured coating and secondarily bonded to the substrate.

#### 4.2 TASK II - EVALUATION OF GO GOVERNMENT FURNISHED THERMAL RESISTANT CERAMIC FELTS

The government furnished ceramic felts were not identified as to composition of the felt structure nor identified as to the coating which was present upon one surface. The felts were on the order of 0.5 inch (1.27 cm) thickness and varied considerably in weight. The following conclusions are based upon thermal insulation effectiveness only.

Specimen No. T-118 yielded the best thermal protection when exposed to a 2300°F (1260°C) frontface temperature, 14 minutes before an aluminum substrate temperature of 500°F (260°C) is reached and 31 minutes until 800°F (427°C) is reached. The next best specimens were T-116, T-129A, T-129B, and T-130A with values in the range of 9 minutes to 500°F (260°C) and 23 minutes to 800°F (427°C).

#### 4.3 TASK III - FABRICATION AND INSTALLATION OF THERMAL BARRIER COATING IN AN A-4 JET COCKPIT

The best coating formulation evaluated in Task I was combined with glass/phenolic honeycomb, prefabricated into precured panels and installed in the



cockpit area. It was determined that the installation could be accomplished without the use of special tooling and is feasible as a field installation. Further evaluations and conclusions can be made when the Naval Weapon Center personnel complete the actual fuel fire test environment evaluation which is scheduled for the latter part of 1976.

#### 4.4 TASK IV - PYREX GLASS MOSAIC OVERLAY OF A-4 JET PLEXIGLAS CANOPY

A mosaic pyrex glass overlay (individual pieces) was installed over the Plexiglas portion of the canopy by adhesively spot-bonding with a transparent silicone adhesive. Image distortment, when viewed from inside the cockpit, was apparent; however, this could be significantly reduced by using a one or two piece preformed pyrex canopy overlay.

Further conclusions as to the effectiveness of this task can be made when Naval Weapon Center personnel complete their testing of this canopy under an actual fire test environment.

APPENDIX A

MATERIALS LIST FOR THE  
ENTIRE PROGRAM

APPENDIX A  
MATERIALS LIST FOR THE ENTIRE PROGRAM

<u>Material</u>	<u>Company Name</u>	<u>Description</u>
Flamarest Epoxy Paint AVCO 1100	AVCO Systems Division	Three component catalyzed epoxy, semi rigid, intumescent coating
Monokote 5	W. R. Grace and Co.	One part fireproofing system mixed with water
Sodium Silicate	L. A. Chemical Co.	
Dow Corning 325 Ablative Silicone	Dow Corning Corp.	Ablative Silicone Rubber
Dow Corning 2106 Silicone Resin	Dow Corning Corp.	Silicone Resin with Catalyst
Latex Compound	B. F. Goodrich	Latex
APF Epoxy Deck Coating	HYSOL	Two part epoxy system with nylon, sand, and asbestos fillers
Butyl Rubber 11.7 Percent Solids	B. F. Goodrich	Butyl Rubber
Urea-Resin Wilhold	Wilhold Glues Inc.	Plastic Resin Adhesive
Carbopol 934	B. F. Goodrich	Water Thickening Agent
50 Percent 828 Epoxy Resin	Shell	Two part epoxy resin system
50 Percent Versamid (140 Polyamid Resin)	General Mills	
35 Percent Magnesium Oxide	L. A. Chemical Co.	
65 Percent Magnesium Chloride		
MXS 6026/84	Fiberite West Coast Corp.	Phenolic Prepreg
ALBI-107A	Sherwin Williams	Intumescent solvent based modified vinyl coating

<u>Material</u>	<u>Company Name</u>	<u>Description</u>
Pittsburgh Speedhyde	PPG Industries Inc.	Latex Fire Retardant Paint
Vermiculite	W. K. Grace Co.	Naturally occurring mineral (hydrous mica)
Perlite	Redco, Inc.	Naturally occurring glassy volcanic rock
Pyrex Glass	Sudden Service Glass Co.	2" x 2" x .25" Pyrex (5.08 x 5.08 x .64 cm)
Safety Wire	National Standard Wire Co.	.015" Diameter (.038 cm)
Brass Bar	Ducommun Metals and Supply Co.	1/4" x 1" (.64 x 2.54 cm)
RTV 108	Electron Specialties (G.E.)	Translucent Silicone Rubber
Phenolic/Glass Honeycomb	Hexcel	3/16 inch (.48 cm) cell size .5 inch (1.27 cm) thick 5.5 lb/ft <sup>3</sup> (88.1 kg/m <sup>3</sup> )
EPI Bond 122 and 952 harder	Furane Plastics Inc.	2 Part Adhesive System

APPENDIX B

THERMAL PROTECTIVE COATING TEST  
MATRIX AND FILLERS OF TASK I

## APPENDIX B

## THERMAL PROTECTIVE COATING TEST MATRIX AND FILLERS OF TASK I

SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT		COATING THICKNESS		WEIGHT	
	MATRIX	FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
1	Flamarest Epoxy Paint Avco 1100 - 29%	Perlite #1120 - 71%	75	(.19)	.47	(2.29)
1 - 1	Same As #1 - 34%	Same As #1 - 66%	97	(.25)	.74	(3.61)
2	Flamarest Epoxy Paint Avco 1100 - 34%	Vermiculite #3 - 66%	75	(.19)	.59	(2.88)
2 - 1	Same As #2 - 32%	Same As #2 - 68%	75	(.19)	.63	(3.07)
3	Flamarest Epoxy Paint Avco 1100 - 34%	Vermiculite #2 - 66%	71	(.18)	.50	(2.44)
3 - 1	Same As #3 - 34%	Same As #3 - 66%	82	(.21)	.61	(2.98)
4	Monokote 5 Zonolite MK-5 Fireproofing	Not Known	32	(.81)	.09	(.44)
4 - 1	Same As #4	Same As #4	61	(.15)	.14	(.68)
5	Sodium Silicate - 34%	Perlite #1120 - 66%	110	(.28)	.59	(2.88)
5 - 1	Same As #5 - 34%	Same As #5 - 66%	100	(.25)	.58	(2.83)
6	Sodium Silicate - 34%	Vermiculite #2 - 66%	52	(.13)	.36	(1.76)
6 - 1	Same As #6 - 34%	Same As #6 - 66%	59	(.15)	.51	(2.49)
7	Dow Corning 325 Ablative Silicone - 34%	Perlite #1120 - 66%	63	(.16)	.57	(2.78)
8	Dow Corning 325 Ablative Silicone - 34%	Vermiculite #2 - 66%	110	(.28)	.62	(3.02)
9	Dow Corning 2106 Silicone Resin - 34%	Perlite #1120 - 66%	100	(.25)	.52	(2.54)
10	Dow Corning 2106 Silicone Resin - 28%	Vermiculite #2 - 72%	76	(.19)	.53	(2.58)
11	Aluminum Control Specimen	None	--		---	

SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT		COATING THICKNESS		WEIGHT	
	MATRIX	FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
12	-0	Flamarest Epoxy Paint	52	(.13)	.38	(1.85)
	-1	Avco 1100 - 100%	51	(.13)	.33	(1.61)
	-2		63	(.16)	.41	(2.00)
13	Flamarest Epoxy Paint Avco 1100 - 34%	Not known Vermiculite #4 - 66%	67	(.17)	.62	(3.02)
14	Latex Compound B.F. Goodrich - 34%	Perlite #1120 - 66%	100	(.25)	.55	(2.68)
15	Latex Compound B.F. Goodrich - 26.4%	Vermiculite #2 - 73.6%	63	(.16)	.52	(2.54)
16	APF 100 Epoxy Deck Coat- ing Aeronutronic Ford	Nylon, sand, asbestos	60	(.15)	.49	(2.39)
17	Flamarest Epoxy Paint Avco 1100 - 43.6%	Perlite #4500 - 56.4%	58	(.15)	.42	(2.05)
18	Dow Corning 325 Ablative Silicone - 100%	Not Known	72	(.18)	.31	(1.51)
19	Butyl Rubber 11.7% Solids - 2.7%	Perlite #1120 - 97.3%	87	(.22)	.46	(2.24)
20	Butyl Rubber 11.7% Solids - 14.6%	Vermiculite #2 - 85.4%	50	(.13)	.44	(2.14)
21	Plastic Resin Glue Urea-Resin Wilhold - 34%	Perlite #1120 - 66%	90	(.23)	.55	(2.68)
22	Plastic Resin Glue Urea-Resin Wilhold - 34%	Vermiculite #2 - 66%	52	(.13)	.46	(2.24)
23	Carbopol 934/H <sub>2</sub> O <sup>2</sup> - 34.5% B.F. Goodrich	Vermiculite #2 - 64.5%	62	(.16)	.38	(1.85)
24	50% Shell 828 Epoxy Resin 50% Gen. Mils Versamid 140 Polyamid Resin - 34%	Aluminum Hydroxide - 66%	62	(.16)	.53	(2.59)
25	Sodium Silicate - 34%	Aluminum Hydroxide - 66%	63	(.16)	.52	(2.54)

SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT		COATING THICKNESS		WEIGHT	
	MATRIX	FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
26	50% Shell 828 Epoxy Resin 50% Gen. Mils Versamid 140 Polyamid Resin - 34.2%	Borax - 65.8%	54	(.14)	.39	(1.90)
27	Sodium Silicate - 62%	Borax - 38%	74	(.19)	.53	(2.59)
28	35% Magnesium Oxide 65% Magnesium Chloride H <sub>2</sub> O 1.17 Density solution 84.8%	Phenolic Micro Balloons - 15.2%	65	(.16)	.23	(1.12)
29	50% Shell 828 Epoxy Resin 50% Gen. Mils Versamid 140 Polyamid Resin - 34%	Potassium Nitrate KNO <sub>3</sub> - 66%	90	(.23)	.56	(2.73)
30	MXS 6026/84 Fiberite Phenolic Prepreg - 100%	Not known	85	(.22)	.72	(3.51)
31	Sodium Silicate - 34%	Vermiculite # 4 - 66%	68	(.17)	.48	(2.34)
32	Dow Corning 325 Ablative Silicone - 34%	Vermiculite #4 - 66%	104	(.26)	.56	(2.73)
32 - 1	Same As #32 - 34%	Same As #32 - 66%	77	(.20)	.56	(2.73)
33	Dow Corning 2106 Silicone Resin - 34%	Vermiculite #4 - 66%	56	(.14)	.49	(2.39)
34	Latex Compound B.F. Goodrich - 25.2%	Vermiculite #4 - 74.8%	67	(.17)	.51	(2.49)
35	Albi 107-A, Vinyl Fire Retardant	Not Known	52	(.13)	.34	(1.66)
35	Albi 107-A - 100%	Not Known	52	(.13)	.34	(1.66)
35 - 1	Albi 107-A - 100%	Not Known	60	(.15)	.39	(1.90)
35 - 2	Albi 107-A - 100%	Not Known	72	(.18)	.48	(2.34)
35 - 3	Albi 107-A - 100%	Not Known	25	(.06)	.16	(.78)
35 - 4	Albi 107-A - 100%	Not Known	45	(.11)	.32	(1.56)
35 - 5	Albi 107-A - 100%	Not Known	70	(.18)	.48	(2.34)
35 - 6	Albi 107-A - 100%	Not Known	110	(.28)	.67	(3.27)
35 - 7	Albi 107-A - 100%	Not Known	135	(.34)	.84	(4.10)



SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT		COATING THICKNESS		WEIGHT	
	MATRIX	FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
36	Albi 107-A, Vinyl Fire Retardant - 34.2%	Perlite #1120 - 65.8%	97	(.25)	.70	(3.42)
36 - 1	Albi 107-A - 34%	Perlite #1120 - 66%	75	(.19)	.49	(2.39)
36 - 2	Albi 107-A - 66%	Perlite #1120 - 34%	80	(.20)	.51	(2.49)
37	Albi 107-A, Vinyl Fire Retardant	Vermiculite #2 -	67	(.17)	.60	(2.93)
37 - 1	Albi 107-A - 34%	Vermiculite #2 - 66%	60	(.15)	.51	(2.49)
37 - 2	Albi 107-A - 66%	Vermiculite #2 - 34%	80	(.20)	.52	(2.54)
38	MXS 6026/84 Fiberite Phenolic Prepreg - 100%	Not Known	89	(.23)	.72	(3.51)
39	MXS 6026/84 Fiberite Phenolic Prepreg - Charred - 100%	Not Known	86	(.22)	.60	(2.93)
40	Albi 107-A - 34%	Vermiculite #1 - 66%	130	(.33)	.92	(4.49)
40 - 1	Albi 107-A - 66%	Vermiculite #1 - 34%	110	(.28)	1.0	(4.88)
41	Albi 107-A - 34%	Vermiculite #3 - 66%	65	(.17)	.51	(2.49)
41 - 1	Albi 107-A - 66%	Vermiculite #3 - 34%	72	(.18)	.54	(2.64)
42	Albi 107-A - 34%	Vermiculite #4 - 66%	65	(.17)	.51	(2.49)
42 - 1	Albi 107-A - 66%	Vermiculite #4 - 34%	65	(.17)	.52	(2.54)
43	Albi 107-A - 34%	Vermiculite #5 - 66%	55	(.14)	.52	(2.54)
43 - 1	Albi 107-A - 66%	Vermiculite #5 - 34%	65	(.17)	.52	(2.54)
44	Albi 107-A - 34%	Perlite #4500 - 66%	72	(.18)	.47	(2.29)
44 - 1	Albi 107-A - 66%	Perlite #4500 - 34%	80	(.20)	.54	(2.64)
45	Albi 107-A - 34%	Perlite #1440 - 66%	83	(.21)	.51	(2.49)
45 - 1	Albi 107-A - 66%	Perlite #1440 - 34%	77	(.20)	.52	(2.54)
46	Albi 107-A - 34%	Perlite #816 - 66%	130	(.33)	.78	(3.81)
46 - 1	Albi 107-A - 66%	Perlite #816 - 34%	120	(.30)	.78	(3.81)
46 - 2	Albi 107-A - 66%	Perlite #816 - 34%	135	(.34)	.85	(4.15)

SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT			COATING THICKNESS		WEIGHT	
	MATRIX		FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
47	Pittsburgh 42-7	- 100%	Not Known	48	(.12)	.26	(1.27)
47 - 1	Pittsburgh 42-7	- 100%	Not Known	43	(.11)	.23	(1.12)
47 - 2	Pittsburgh 42-7	- 100%	Not Known				
48	Pittsburgh 42-7	- 34%	Vermiculite #2 - 66%	78	(.20)	.52	(2.54)
49	Pittsburgh 42-7	- 34%	Perlite #1120 - 66%	85	(.22)	.55	(2.68)
50	Albi 107-A	- 33.8%	Vermiculite #3 - 65.8% HTS Carbon Fiber .4% 3" length	80	(.20)	.52	(2.54)
50 - 1	Albi 107-A	- 65.84%	Vermiculite #3 - 33.86% HTS Carbon Fiber, 0.3% 3" length	60	(.15)	.52	(2.54)
50 - 2	Albi 107-A	- 65.84%	Vermiculite #3 33.86% HTS Carbon fiber, 0.3% Short 1/2" fiber	60	(.15)	.54	(2.63)
51	Albi 107-A	- 66%	Vermiculite #5 34% Carbon cloth 2 ply from T-75 fiber	50	(.12)	.37	(1.81)
52	Albi 107-A	- 34%	Vermiculite #2, 33% #5, 33%	65	(.17)	.51	(2.49)
52 - 1	Albi 107-A	- 66%	Vermiculite #2, 17% #5, 17%	50	(.12)	.56	(2.73)
53	Albi 107-A	- 34%	Layers #5, 33% Vermiculite #2, 33%	74	(.19)	.53	(2.59)
53 - 1	Albi 107-A	- 66%	Layers #5, 17% Vermiculite #2, 17%	70	(.18)	.59	(2.88)
54	Albi 107-A	- 34%	Layers Vermiculite #5 - 33% Perlite 4500 - 33%	70	(.18)	.52	(2.54)
54 - 1	Albi 107-A	- 66%	Layers Same as 54 Vermiculite #5 - 17% Perlite 4500 - 17%	80	(.20)	.55	(2.68)

SPECIMEN NO.	COATING FORMULATION AND PERCENT BY WEIGHT		COATING THICKNESS		WEIGHT	
	MATRIX	FILLER	MILS	(CM)	LBS/FT. <sup>2</sup>	(kg/m <sup>2</sup> )
55	Albi 107-A	- 34% Crocidolite asbestos - 0.2% Vermiculite #2 - 65.09%	60	(.15)	.49	(2.39)
55 - 1	Albi 107-A	- 66% C/asbestos - .53% Vermiculite #2 - 33.47%	60	(.15)	.55	(2.68)
55 - 2	Albi 107-A	- 66% C/asbestos - .53% Vermiculite #2 - 33.47%	75	(.19)	.56	(2.73)
56	Albi 107-A	- 54% C/asbestos - 0.2% Perlite 1120 - 65.09%	95	(.24)	.5	(2.44)
56 - 1	Albi 107-A	- 66% C/asbestos - .53% Perlite 1120 - 65.06%	85	(.22)	.54	(2.64)
57	Albi 107-A	- 79% Glass Bubbles B25B (3M) - 21%	60	(.15)	.15	(.73)
57 - 1	Albi 107-A	- 90% Glass Bubbles B25B (3M) - 10%	80	(.20)	.27	(1.32)
58	Albi 107-A	- 79% Eccospheres Ft. 102 (E.C.) - 21%	60	(.15)	.15	(.73)
58 - 1	Albi 107-A	- 90% Eccospheres FT 102 (E.C.) 10%	85	(.22)	.28	(1.37)
59	Albi 107-A	- 66% 3" Carbon fibers - .53% Vermiculite #2 - 33.47%	76	(.19)	.57	(2.78)
60	Albi 107-A	- 66% C/asbestos fiber - .53% Vermiculite #2 - 33.47%	6 x 6 sample on 8" x 8" plate, tested with plate toward heat			
61	Albi 107-A	- 99.51% 3" carbon fibers, HTS -.49%	70	(.18)	.48	(2.34)
62	Albi 107-A	- 99.51% C/asbestos fiber - .49%	63	(.16)	.47	(2.29)

APPENDIX C

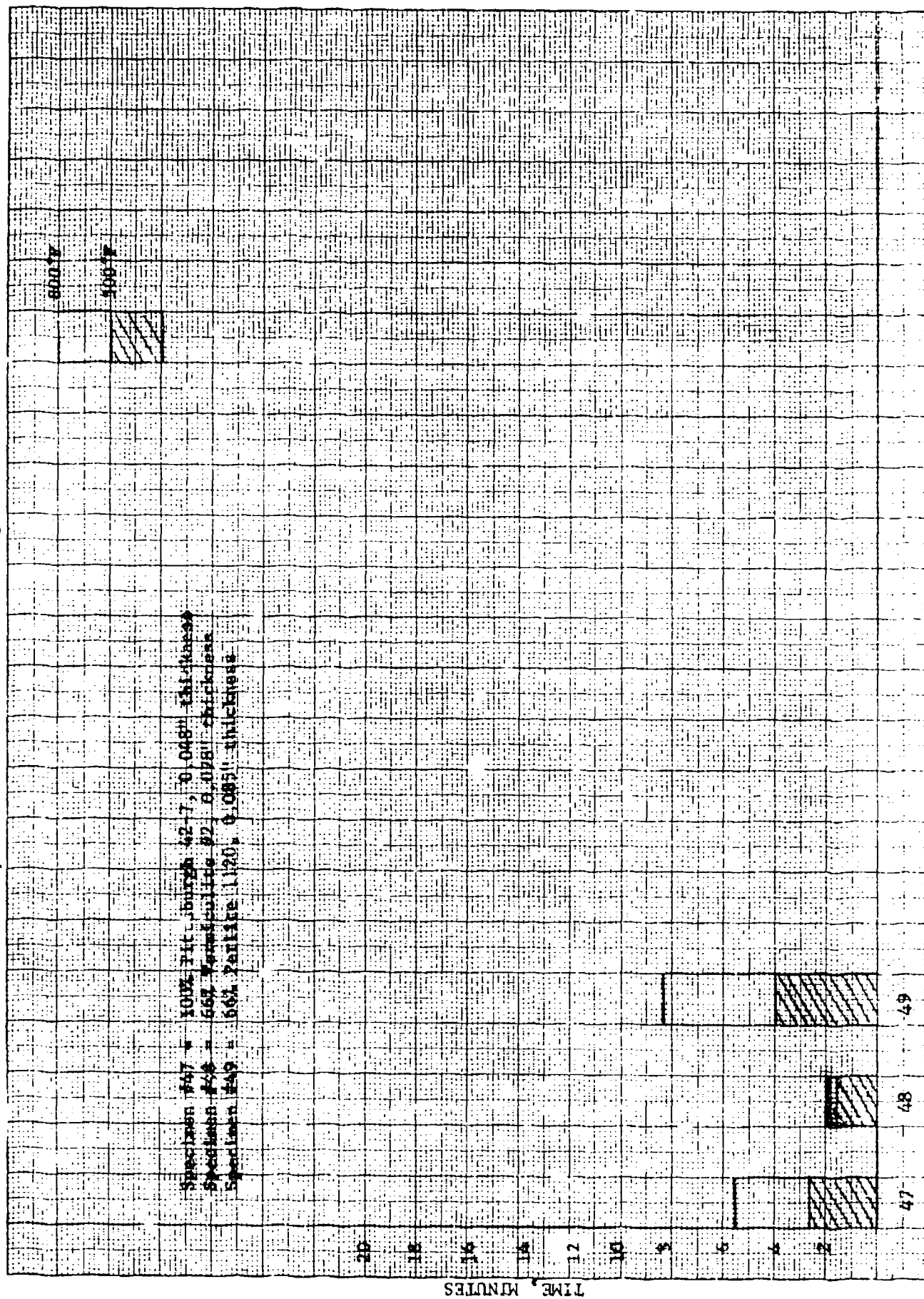
SUBSTRATE BACKFACE THERMAL RESPONSE FOR THE MOST  
SIGNIFICANT SPECIMENS TESTED IN TASK I

KOE 10 X 10 TO THE CENTIMETER 46 1513

10 X 2.5 CM

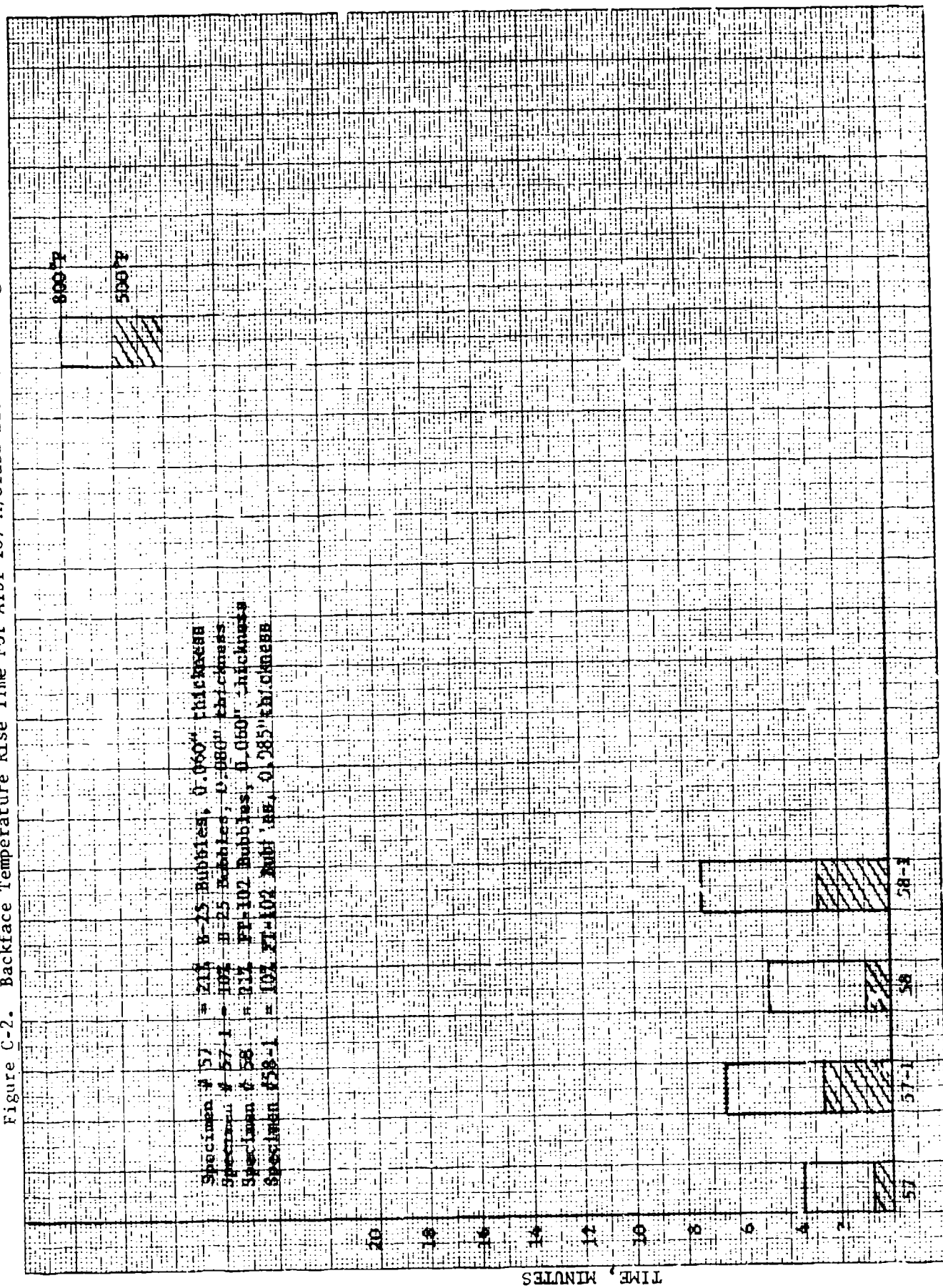
KRIFFEL A. C. 11.11.10

Figure C-1. Backface Temperature Rise Time For Pittsburgh 42-7 Coating With Various Fillers



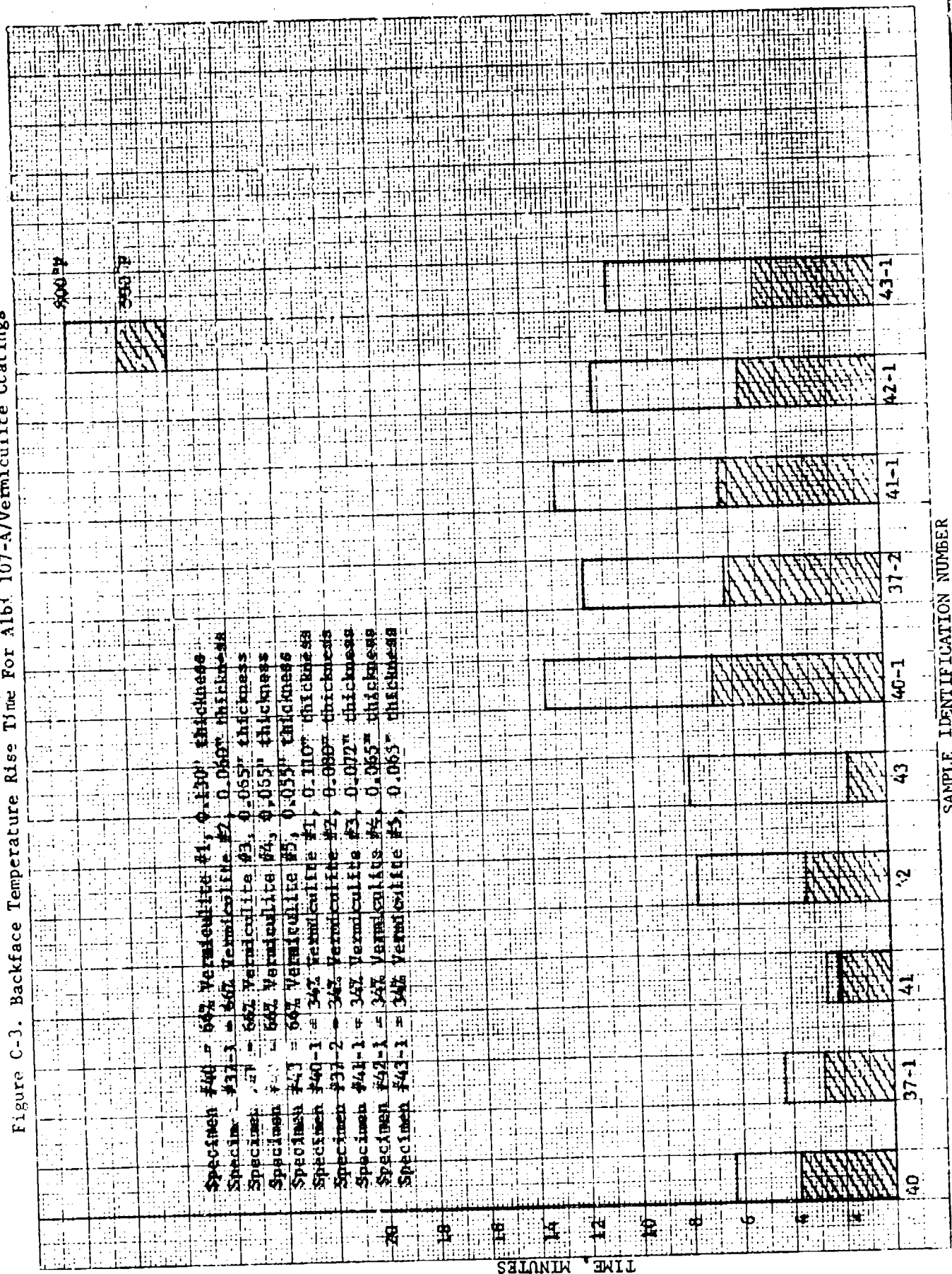
SAMPLE IDENTIFICATION NUMBER

Figure C-2. Backface Temperature Rise Time For Albi 107-A/Glass Bubble Coatings



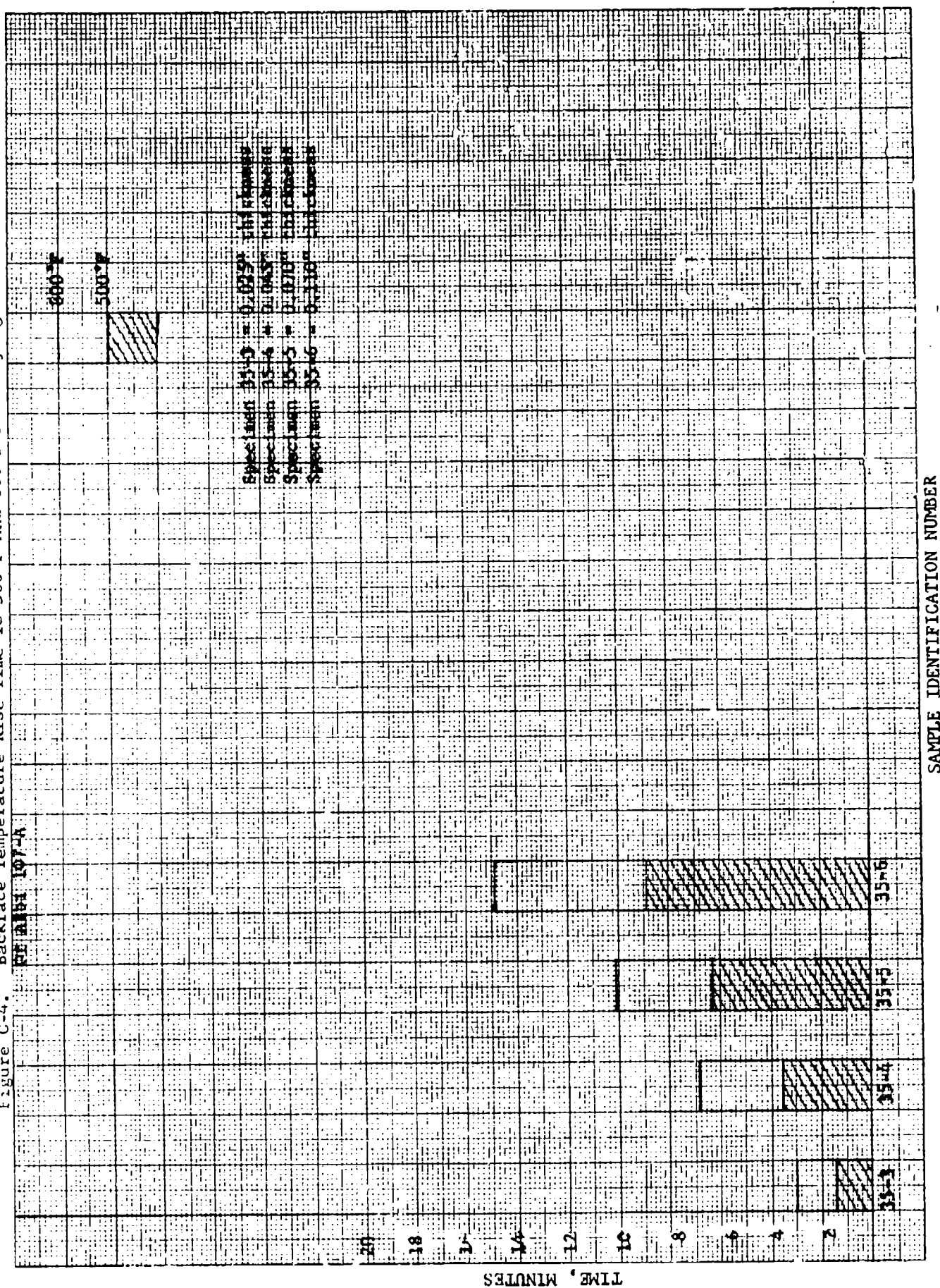
K-5 10 X 10 1/2 INCHES 48 12 12

Figure C-3. Backface Temperature Rise Time For Alb 107-A/Vermiculite Coatings



SAMPLE IDENTIFICATION NUMBER

Figure C-4. Backface Temperature Rise Time To 500°F And 800°F For Varying Thicknesses





NO 10 X 10 TO THE CLINT MILE 40 1513

Figure C-5. Backface Temperature Rise Time For Albi 107-A/Perlite Coatings

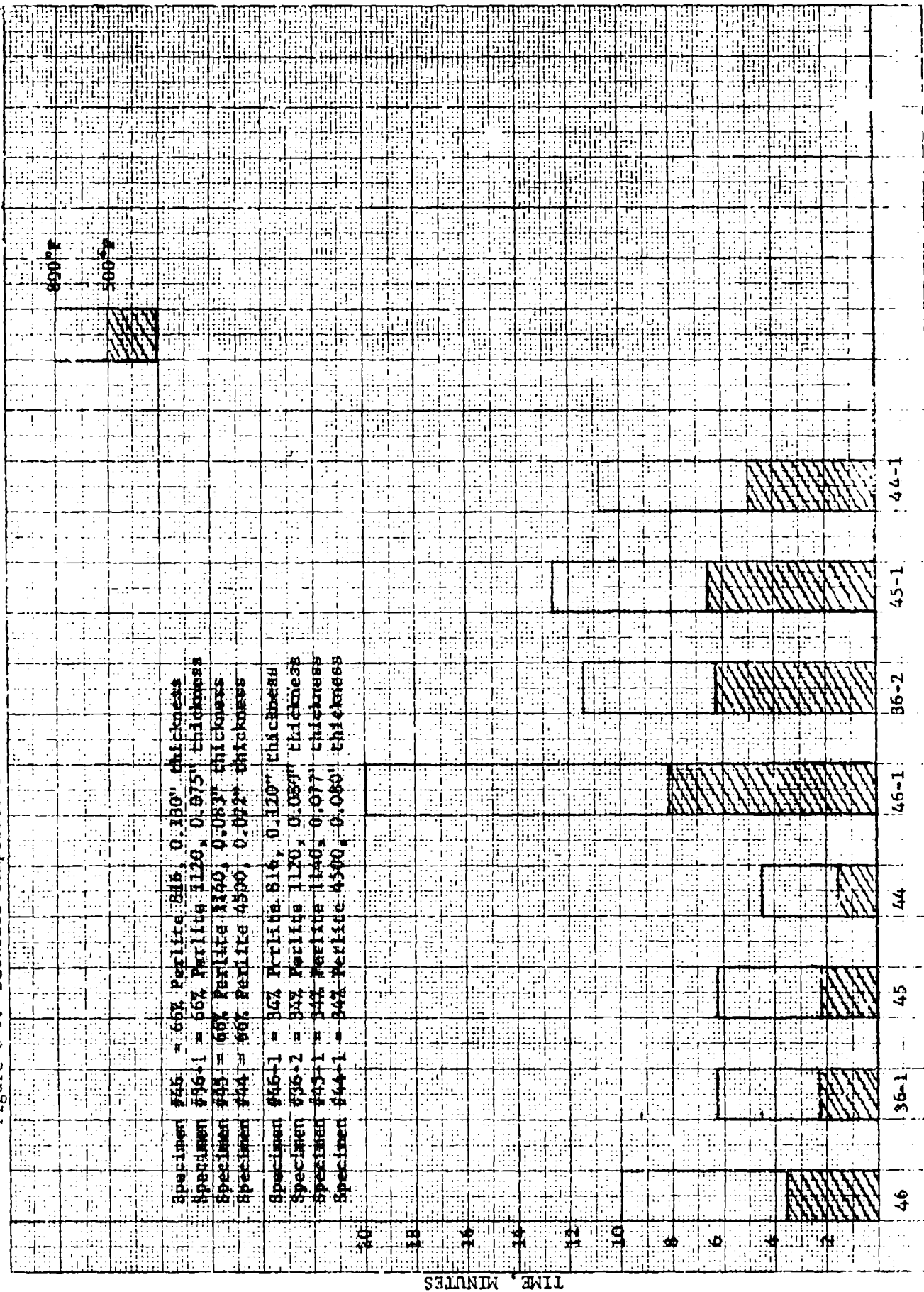




Figure C-7. Backface Temperature Rise Time For Albi 107-A With Various Fillers

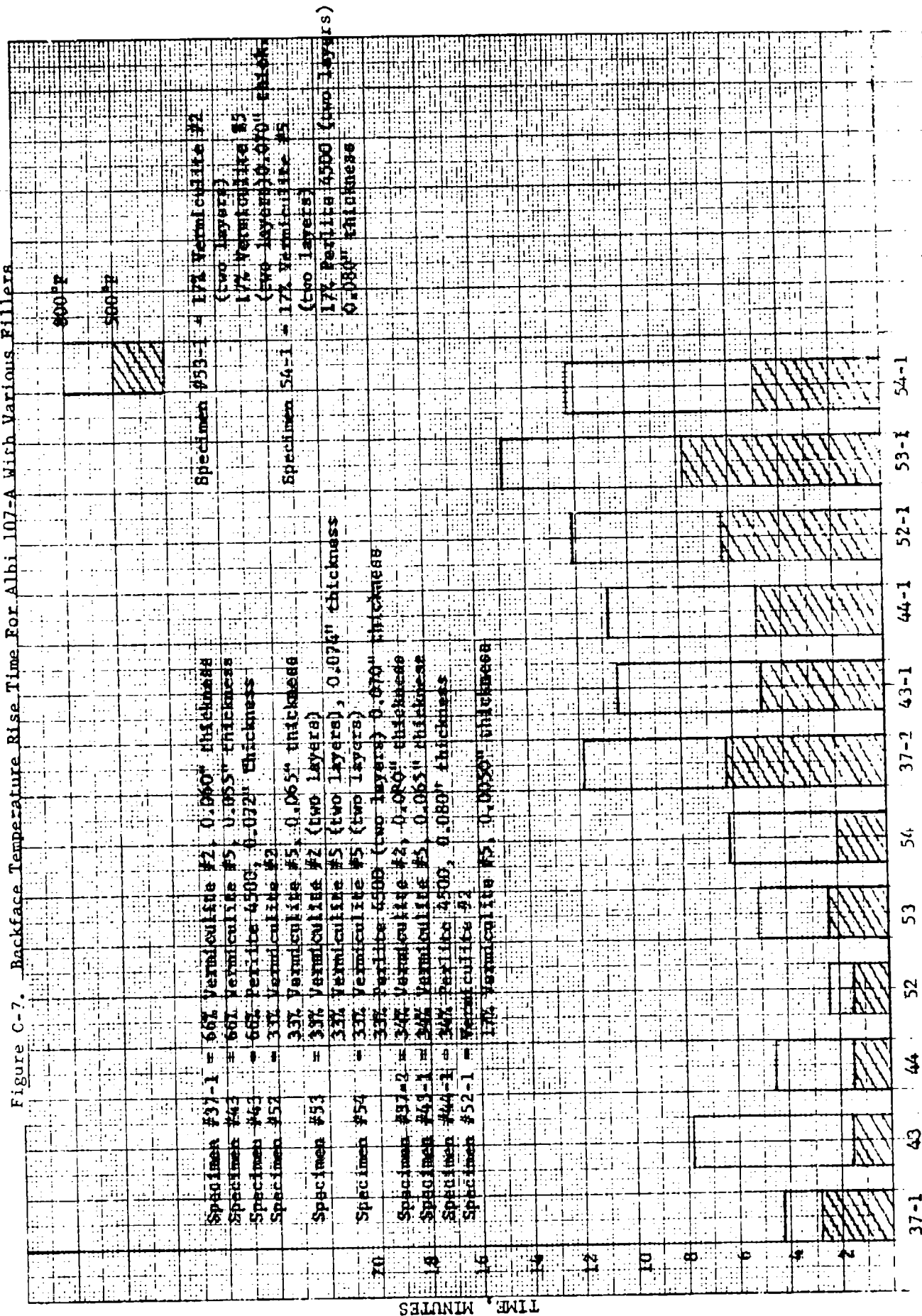
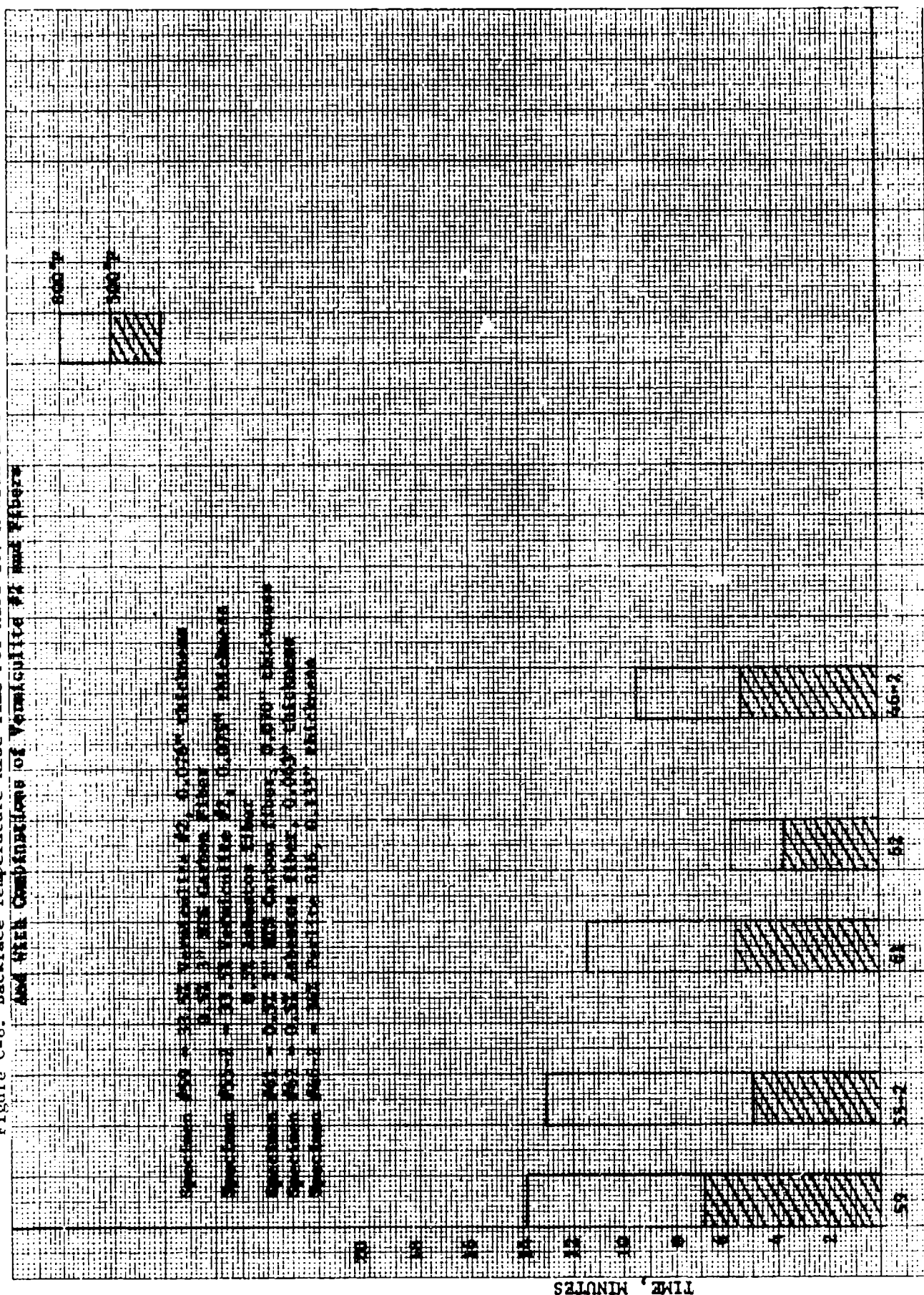


Figure C-8. Backface Temperature Rise Time For Albi 107-A With Fibrous Filler And 45% Combinations of Vermiculite #2 and Fibers



APPENDIX D

PHYSICAL PROPERTIES AND THERMAL RESPONSE  
DATA OF TASK II

TABLE D.1 THERMAL RESPONSE DATA OF TASK II

Time	Seconds					Minutes															
Specimen Number	0	10	20	30	40	Degrees Celsius															
T-1	23.8		42.2	46.6		238	208	167	81.1	280	264	316	346	371	393	424					
T-2	23.8	35.6	65.5	66.1		314	282	176	66.1	371	342	422									
T-3	26.1	26.7	53.9	77.9		255	214	82.2	77.8	312	289	339	377	392	433						
T-4	26.7	29.4	55.6	67.8		269	204	113	73.9	330	306	358	385	414							
T-5	28.9	31.1	66.1	68.9		294	265	207	71.1	355	323	385	412	434							
T-6	28.3	30.0	69.4	75.6		287	258	174	75.6	340	313	367	394	420	449						
T-7	27.2	29.4	69.4	71.3		268	229	140	65.5	326	299	353	378	399	427						
T-8	23.8	25.0	59.4	71.7		279	246	114	73.9	348	313	382	410	439							
T-9	23.8	30.0	40.0	51.8		300	274	233	127	327	299	338	371	391	410						
T-10	25.6	31.1	60.5	81.3		216	188	103	83.3	289	264	320	362	368	401	427+					
T-11	26.7	35.6		67.2		262	218	150	69.4	309	288	327	352	376	398	427+					
T-12	28.9	36.1		51.6		234	194	141	67.2	294	272	303	318	336	358	391	428				
T-13	25.6	26.7	58.3	66.7		251	189	91.7	63.3	318	293	346	366	375	396	427+					
T-14	23.8	31.1		42.2		277	244	169	63.3	311	296	331	351	368	398	420	432				
T-15	25.6	31.7	40.6	42.2		238	213	159	58.9	299	277	342	378	405	434						
T-16	23.8	33.3	42.2	44.4		245	212	156	60.0	297	272	343	378	402	419						
T-17	23.8			40.0		207	207	150	53.3	291	268	309	349	369	405	423					
T-18	26.1	27.2	30.0	37.8		208	208	146	52.2	283	264	299	317	327	343	382	401	414			
T-19	21.8	28.9	33.3	37.8		232	232	185	86.7	302	297	341	367	391	427+						
T-20	27.2	30.6	40.6	43.9		242	204	158	76.7	291	271	307	324	359	387	406	427				
T-21	26.1	28.9	35.6	40.0		261	215	169	50.0	297	280	340	376	406	432						
T-22	26.7	37.8	43.9	61.1		227	227	186	126	306	282	333	367	388	429						
T-23	26.1	29.4	51.1	80.0		264	264	230	162	314	294	371	378	409	428						
T-24	23.8	29.4	49.4	93.9		299	270	247	182	354	319	391	409	426							
T-25A	23.8	37.2	52.8	55.6		301	278	234	107	340	321	389	428								
T-26	23.8	40.6		53.3		283	253	212	93.9	322	306	371	418								
T-27	23.8	53.3	55.6	62.2		291	258	216	117	346	318	391	411	432							
T-28	23.8	55.0	55.6	67.2		280	250	213	128	333	308	367	409	429							
T-29	23.8	46.7	49.4	60.6		270	238	213	131	327	296	382	429								
T-30	23.8	36.7		62.8		276	248	212	134	322	299	372	414								
T-104	23.8	25.0	32.2	51.1		252	221	183	113	298	278	340	378	413							
T-105	25.0		31.7	43.3		260	227	189	100	303	284	336	368	406	423						

TABLE D.1. THERMAL RESPONSE DATA OF TASK II (Continued)

Time	Seconds				Minutes															
	0	10	20	30	1	2	3	4	5	6	7	8	9	10	12	14	16	18	24	
Specimen Number	Degrees Celsius																			
T-106	19.4	23.8	51.7	88.3	179	242	272	295	320	347	366	393	422	444						
T-107	21.1		31.1	50.0	116	192	227	258	280	299		336		367	396	425				
T-108	26.1	32.2		46.1	70.0	162	218	249	279	296		330		363	397	434				
T-109	26.7	36.7		46.7	77.2	167	210	240	266	284		320		356	384	412				
T-110	28.9	31.1		42.2	65.0	142	191	218	246	266		301		332	360	381	404	433		
T-111	26.1	35.6	47.2	50.6	74.4	160	205	235	263	281		311		338	364	386	410			
T-112	23.8	37.8	50.0	57.2	83.3	184	227	256	283	289	325	347	365	383	414					
T-113	23.8	33.9		46.1	82.8	180	221	254	274	296		332		368	398	432				
T-114	23.8	37.8		47.2	83.9	183	225	254	281	299		339		376	405	436				
T-116	23.8		32.2	37.8	47.2	58.9	93.3	137	171	199		244		274	295	313	327	348	27 Min 432	
T-118	23.8		29.4		40.0	70.0	97.2	119	137	143	168	187		213	238	262	282	298	352 31 Min 427	
T-119B	21.1	72.8	138	189	258	319	364	409												
T-119C	23.8	95.0	159	198	253	323	380	429												
T-120	23.8	25.0	28.9	35.6	66.7	151	204	240	271	299		352		388	414					
T-121	22.2	30.0	38.9	54.4	124	213	270	304	349	341	422									
T-122A	22.2	23.8		51.1	108	189	233	260	285	302		341		396	405	422				
T-122B	23.8	29.4	42.8	66.1	145	233	269	297	317	339		385		422						
T-124	21.1	28.9	40.0		80.0	185	225	250	272	287		312		343	368	387	405	431		
T-125	23.8	33.3	43.8	47.2	66.7	196	260	278		316		343		378	414					
T-126	26.7	35.0		46.7	91.1	172	221	254	286	301		329		358	392	427				
T-127	25.6	31.1	35.0	38.9	77.2	180	237	243	264	285	297	308		343	378	408				
T-128A	26.1	33.3	38.3	43.9	83.9	175	217	248	274	296		327		361	388	423				
T-128B	27.2	33.9		46.1	86.1	180	218	251	276	296	311	330		361	396	422				
T-129A	25.0		28.9		38.9	68.3	77.8	77.8	118	147		200		250	289	312	286	346	27 Min 440	
T-129B	25.0		35.6		67.8	71.1	117	162	196	226		275		322	354	377	390	410	20 Min 434	
T-130A	23.8			31.1	51.1	63.3	94.4	144	179	208		258		299	334	363	387	412	20 Min 436	
T-130B	23.8	25.0	28.9	31.7	51.1	71.1	76.1	130	176	209		266		311	349	387	422			
T-131A	28.9	28.9	36.7	53.9	68.9	68.3	107	158	191	224		274		316	352	384	403	437		
T-131B	23.8	23.8	35.0	48.9	58.3	74.4	128	162	193	225		282		322	357	380	400	419		
T-S-1	23.8	36.7	53.3	51.7	71.1	176	211	241	264	286		325		373	403	432				
T-S-2	25.0	31.1	61.1		77.2	214	249	283	311	336		390		433						

TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II

Specimen No.	Date Tested	Thickness		Weight	
		(in.)	(cm)	(lbs/ft <sup>2</sup> )	(kg/m <sup>2</sup> )
T-1	11-20-75	0.47	1.19	0.43	2.10
T-2	12-2-75	0.39	0.99	0.77	3.76
T-3	12-2-75	0.40	1.02	0.73	3.56
T-4	12-2-75	0.41	1.04	0.69	3.37
T-5	12-2-75	0.37	0.94	0.64	3.12
T-6	12-1-75	0.41	1.04	0.74	3.61
T-7	11-20-75	0.38	0.96	0.75	3.66
T-8	11-20-75	0.36	0.91	0.70	3.42
T-9	11-19-75	0.465	1.18	0.31	1.51
T-10	11-18-75	0.44	1.12	0.81	3.95
T-11	11-18-75	0.445	1.13	0.63	3.08
T-13	11-18-75	0.50	1.27	0.58	2.83
T-14	11-11-75	0.43	1.09	0.81	3.95
T-15	12-5-75	0.48	1.22	0.51	2.49
T-17	12-5-75	0.53	1.35	0.51	2.49
T-18	12-5-75	0.55	1.40	0.61	2.98
T-19	11-19-75	0.50	1.27	0.48	2.34
T-20	11-19-75	0.51	1.30	0.50	2.44
T-21	11-19-75	0.45	1.14	0.35	1.71
T-22	11-19-75	0.48	1.22	0.37	1.81
T-23	11-19-75	0.45	1.14	0.40	1.95



TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE  
WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II  
- (Continued)

<u>Specimen No.</u>	<u>Date Tested</u>	<u>Thickness</u>		<u>Weight</u>	
		<u>(in.)</u>	<u>(cm)</u>	<u>(lbs/ft<sup>2</sup>)</u>	<u>(kg/m<sup>2</sup>)</u>
T-24	11-19-75	0.465	1.18	0.22	1.07
T-26	11-19-75	0.43	1.09	0.20	0.98
T-27	11-19-75	0.44	1.12	0.19	0.93
T-51A	12-5-75	0.49	1.24	0.41	2.00
T-51B	12-5-75	0.48	1.22	0.37	1.81
T-52A	12-2-75	0.45	1.14	0.37	1.81
T-52B	12-3-75	0.45	1.14	0.33	1.61
T-53	12-9-75	0.44	1.12	0.33	1.61
T-54	12-3-75	0.45	1.14	0.35	1.71
T-104	12-4-75	0.44	1.12	0.28	1.37
T-105	12-4-75	0.49	1.24	0.32	1.56
T-106	12-4-75	0.45	1.14	0.21	1.03
T-107	12-4-75	0.48	1.22	0.29	1.42
T-108	12-3-75	0.51	1.30	0.49	2.39
T-109	12-3-75	0.50	1.27	0.47	2.29
T-110	12-3-75	0.54	1.37	0.52	2.54
T-111	12-3-75	0.55	1.40	0.48	2.34
T-112	12-3-75	0.52	1.32	0.44	2.15
T-113	12-4-75	0.58	1.47	0.40	1.95
T-114	12-4-75	0.53	1.35	0.39	1.90

TABLE D.2. LIST OF DATES OF TESTING, THICKNESS, AND SURFACE  
WEIGHT OF THERMAL RESISTANT CERAMIC FELTS OF TASK II  
- (Continued)

Specimen No.	Date Tested	Thickness		Weight	
		(in.)	(cm)	(lbs/ft <sup>2</sup> )	(kg/m <sup>2</sup> )
T-116	12-2-75	0.56	1.42	1.02	4.98
T-118	12-2-75	0.44	1.12	1.42	6.93
T-119B	12-9-75	0.18	0.46	0.08	0.39
T-119C	12-9-75	0.14	0.36	0.07	0.34
T-120	12-4-75	0.38	0.96	0.71	3.47
T-121	12-5-75	0.29	0.74	0.53	2.59
T-122A	12-5-75	0.52	1.32	0.51	2.49
T-122B	12-5-75	0.41	1.04	0.35	1.71
T-124	12-9-75	0.56	1.42	0.38	1.85
T-125	11-11-75	0.56	1.42	0.42	2.05
T-126	11-11-75	0.535	1.36	0.38	1.85
T-127	11-11-75	0.59	1.50	0.36	1.76
T-128A	12-3-75	0.57	1.45	0.33	1.61
T-128B	12-3-75	0.54	1.37	0.35	1.71
T-129A	11-20-75	0.67	1.70	1.33	6.49
T-129B	11-20-75	0.64	1.63	0.81	3.95
T-130A	11-20-75	0.68	1.73	0.81	3.95
T-130B	12-1-75	0.71	1.80	1.06	5.18
T-131A	12-4-75	0.78	1.98	1.13	5.52
T-131B	12-4-75	0.595	1.51	0.83	4.05
T-S-1	12-9-75	0.50	1.27	0.53	2.59
T-S-2	12-9-75	0.43	1.09	0.59	2.88

TABLE D.3. DATA FROM ALUMINUM CONTROL AND CALORIMETER RUNS IN TASK II

<u>Control No.</u>	<u>Date Tested</u>	<u>Time at 500°F (sec) (260°C)</u>	<u>Time at 800°F (sec) (426.7°C)</u>	<u>Radiant Heat</u>	
				<u>BTU/ft<sup>2</sup>sec</u>	<u>Joules/cm<sup>2</sup>sec</u>
AC-1	11-11-75	14.3	24.9		
AC-2	11-11-75	14.5	25.0	15.5	17.6
AC-5	11-19-75	16.6	27.0	15.5	17.6
AC-6	11-20-75	19.2	35.5		
AC-8	12-1-75	17.4	32.5	15.3	17.4
AC-9	12-2-75	16.6	29.6	14.6	16.6
AC-10	12-2-75	16.2	33.5	14.6	16.6
AC-11	12-3-75	16.1	33.4	15.3	17.4
AC-12	12-4-75	14.9	30.4		
AC-13	12-5-75	17.8	33.1	15.1	17.03
AC-14	12-9-75	18.5	35.0	14.6	16.6

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